INTEGRATED CONCEPTUAL DESIGN OF JOINED-WING SENSORCRAFT USING RESPONSE SURFACE MODELS.

THESIS

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Abstract

This study performed a multidisciplinary conceptual design and analysis of Boeing's joined-wing SensorCraft. The joined wing aircraft concept fills a long dwell multi-spectral reconnaissance DOD need, incorporating an integral embedded antenna structure within the wing skin. This analysis was completed using geometrical optimization, aerodynamic analyses, and response surface methodology on a composite structural model. Structural optimization was not performed, but data connectivity between the geometric model and the Finite Element Model was demonstrated, to enable follow-on structural optimization efforts.

Phoenix Integration's Model Center was used to integrate the sizing and analysis codes found in Raymer's text, "Aircraft Design: A Conceptual Approach" as well as those from the NASA derived conceptual design tool AirCraft Synthesis (ACSYNT), and a modified Boeing Finite Element Model (FEM). MATLAB codes were written to modify a NASTRAN structural grid model based on any alteration of the design variables throughout the structure. A concept validation model was also constructed based on the S-3 Viking and Take-off Gross Weight (TOGW) values were found to be within 4 % of actual published aircraft values.

Seven design variables were perturbed about the Boeing solution to determine the response of the joined wing model to the design changes and response surfaces were plotted and analyzed, to drive the solution to the lowest TOGW. The design variables are: overall wing span (b), front wing sweep (Λ_{ib}), aft wing sweep (Λ_{ia}), outboard wing sweep

(Λ_{ob}), joint location as a percentage of half span (j_{loc}), vertical offset of the aft-wing root (z_{fa}) and airfoil thickness to chord ratio (t/c).

This research demonstrated the utility of integrated low-order models for fast and inexpensive conceptual modeling of unconventional aircraft designs. Wind tunnel and flight data would allow a more in-depth evaluation of the performance and accuracy of the codes, and a structural optimization based on several different load cases, including gust loads at zero fuel weight (ZFW) would provide better predictions of structural weight data.

Dedication

"To God belong wisdom and power; counsel and understanding are his."

Job 12:13

I am most grateful to my God and Savior the Lord Jesus Christ, the author of all things, for his guidance, and inspiration in this work. If anything is excellent, it is because He had a hand in it. I am also deeply indebted to my wife, and my five children for their patience and understanding while I was "working on my thesis."

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I would like to express my sincere appreciation to my thesis advisor, Dr. Robert Canfield for his guidance and instruction throughout this thesis effort. His abundant patience and encouragement were immensely helpful.

I greatly appreciate the review of this work by Dr. David Jacques, Dr. Donald Kunz, and Dr. Maxwell Blair. Their honest critique, insight, experience, and direction were greatly valued.

Finally, I would like to recognize my family. I could not have completed this endeavor without the loving support and encouragement of my wife and five children. They deserve the lion’s share of appreciation.

“Sons are a heritage from the LORD, children a reward from him. Like arrows in the hands of a warrior are sons born in one's youth. Blessed is the man whose quiver is full of them.” Psalm 127:3-5

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List of Symbols

Symbol	Definition
α	Angle of Attack
ρ	Air Density
Λ	Wing Sweep Angle
b	Half-Wing Span
c	Wing Chord Length
ft	Feet
g	Acceleration Due to Gravity
hr	hour
ksi	Thousand Pounds per Square Inch
m	Meters
q	Dynamic Pressure
s	Seconds
t	Element Thickness
x	Cartesian Coordinate
y	Cartesian Coordinate
z	Cartesian Coordinate
C	Specific Fuel Consumption
D	Drag
E	Endurance
F	Forces
L	Lift
Pa	Pascals

Symbol	Definition
R	Range
S	Wing Surface Area
V	Velocity, Volume
W	Weight
X	Sample Value

INTEGRATED CONCEPTUAL DESIGN OF JOINED-WING SENSOR-CRAFT USING RESPONSE SURFACE MODELS

I. Introduction

Motivation

SensorCraft is an aircraft developmental concept, derived from a U.S. Air Force need to provide next generation persistent multi-spectral intelligence, surveillance and reconnaissance (ISR). The high-altitude long-endurance (HALE) unmanned air vehicle (UAV) will exhibit long-dwell capabilities and integrate available and future sensors. However, in order to achieve both high endurance and superior radar performance, new aerodynamic designs are required. One candidate platform is based on a joined-wing configuration (Fig. 1), permitting enhanced 360° radar coverage, increased endurance, and a lighter structural weight, typically correlating to lower production costs.

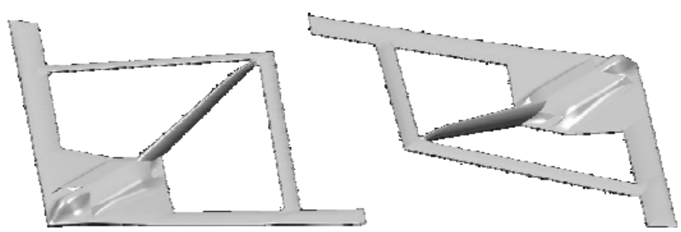


Figure 1 Boeing Joined-Wing SensorCraft (Model 410C)

Problem Statement

These concepts are not without problems and their innovation in form casts a great barrier to the use of conventional design and algorithms based on historical trends. Non-linear responses and other obstacles prevent oversimplification achievable with a linear system. The “build and fly” technique previously employed is simply not cost feasible. The current thrust of industry is in reducing the effort, time and cost of

manufacturing and testing through use of computerized modeling and simulation and this integrated modeling technique was investigated for the Boeing joined-wing SensorCraft concept.

Aircraft design is by nature iterative and susceptible to large unforeseen responses to small changes in design variables. In short, “everything affects everything else.” The typical design scenario requires teams of experts in various disciplines (aerodynamics, structural, control, etc.) working together and passing information “over the fence” to the other teams. It is often unclear what the current baseline model is, and tenuous to keep the teams utilizing exactly the same design data. Integration of data and effort is needed.

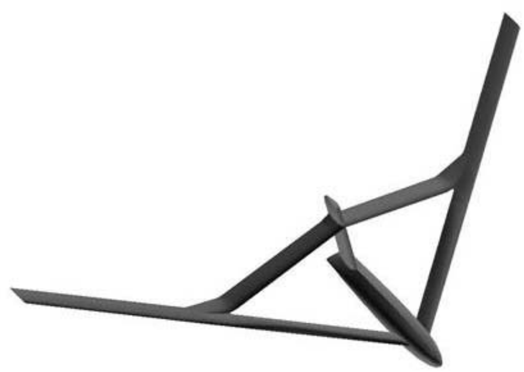


Figure 2 AFIT/AFRL Joined-Wing SensorCraft

Finite element, aero-elastic, and aerodynamic models have been developed for the in-house Air Force Institute of Technology/Air Force Research Lab (AFIT/AFRL) joined-wing SensorCraft design. (Fig. 2) They were previously integrated into a cohesive model through Air Vehicles Technology Integration Environment (AVTIE) an Adaptive Modeling Language (AML) program written by Dr. Max Blair (ref. 1); however, major changes to the model required significant AML reprogramming and code restructuring.

A more easily adaptable model was desired, based on the current Boeing joined-wing SensorCraft Model. The focus of this research is to develop an integrated, scalable model in Phoenix Integration's ModelCenter (ref. 6) that incorporates mission profiles, a modifiable finite element model, and aerodynamics for the Boeing joined-wing SensorCraft configuration, which can be adapted and refined if more fidelity is needed or as requirements change.

Overview

This work attempts to mark out and evaluate a strategy to overcome some of the design obstacles previously mentioned: namely, lack of integration, speed of redesign and heavy reliance on historical data, when dealing with unconventional designs. Phoenix Integration's ModelCenter provided the integration environment to tie all of the model data together in a single place, linking sizing routines and aerodynamic formulas from Raymer (ref. 2), input/output data from AirCraft Synthesis (ACSYNT C), a legacy NASA FORTRAN design code rewritten in C (ref. 3), as well as structural data from Boeing's Finite Element Model (FEM). Having all the data connected meant less time rekeying input files and more time analyzing and optimizing the design. Instead of just answering the question "Will the design fly?" an integrated approach allows one to ask and answer the question "Is the design optimal?"

A primary purpose of this study was to establish a confidence level in the ability of the NASA derived conceptual sizing code ACSYNT coupled to a NASTRAN Finite Element Model (FEM) within ModelCenter to analyze unconventional designs such as the joined wing. The first step consisted of creating and analyzing a validation model in

ModelCenter based on a current conventional aircraft design, the S-3 Viking. Expected fidelity is a calculated Take-off Gross Weight (TOGW) within ten percent of the actual aircraft TOGW.

Based on available aircraft data (refs. 4, 5), an S-3 model was constructed in Model Center and analyzed with ACSYNT and historical codes. Two separate mission profiles were attempted, one based on Raymer’s hypothetical Anti-Submarine Warfare (ASW) mission (ref. 2 - chap3) and one based on one of the actual ASW missions contained in the S-3 NATOPS (ref. 4). Results obtained were then compared with data from the documented flight performance of the vehicle in NATOPS. Previous studies have shown that ACSYNT is capable of calculating aircraft weights to within 10 % of the actual weight. (ref. 5) This study showed that ACSYNT was within 4 % in calculating the gross weight of the S-3 model and 12 % in predicting fuel weight for conventional designs. Raymer’s (ref. 2) initial and refined approaches, discussed in chapters 3 and 6 of the text, underestimated TOGW by 17 and 27% respectively.

Next a semi-conventional canarded ASW aircraft model was constructed, to serve as an unconventional validation model, derived from Raymer’s ASW example (ref. 2), described in chapter 3 of the text and detailed in chapter 3 of this document. Loosely based on Lockheed’s S-3 Viking, the sizing can be expected to be within 10-15% of the S-3’s actual weight – with similarly varying component weights, assuming the mission given is comparable with typical S-3 mission profiles.

Finally a joined wing model was constructed from the available Boeing SensorCraft data (ref. 21), and together with ACSYNT results, Finite Element Analysis (FEA) structural weights were compared with the given Boeing technical data, providing

some idea of the fidelity of the model. Results gave a TOGW for the joined wing model within 1.9 % of the baseline (410D) model.

The model was then perturbed to investigate the response of the joined wing model to the seven design variables, creating an array of varying geometric configurations for the joined-wing aircraft. The design variables are shown in figure 3 and include: half-wing span (b), leading-edge front wing sweep (Λ_{ib}), trailing edge aft wing sweep (Λ_{ia}), leading-edge outboard wing sweep (Λ_{ob}), joint location as a percentage of half span (j_{loc}), vertical offset of the aft-wing root (z_{fa}) and airfoil thickness to chord ratio (t/c). Geometric optimization, aerodynamic analyses, and response surface methodology were tied together in ModelCenter to determine the optimum configuration (lowest-weight) and to determine the relative impact of each design variable on the design.

The use of response surface methodology allows the aircraft designer to more completely comprehend the complex interactions between the design variables and provide the optimal parameters for a joined-wing concept. As mathematical surrogates, response surfaces allow very rapid run times on complex models: on the order of 12 times faster in this study. If well fitted, these mimic with great accuracy the behavior of the complete model. This rapid run time enables the designer to flesh out the design space in a fraction of the computational time that would be required for the entire model.

As a result of this research, response surfaces were generated for important performance measures, a sensitivity analysis of the baseline joined-wing SensorCraft design (model 410E) was accomplished and the design trade space was evaluated in order

to depict more fully the nature of the joined-wing SensorCraft design problem and guide continuing joined wing design.

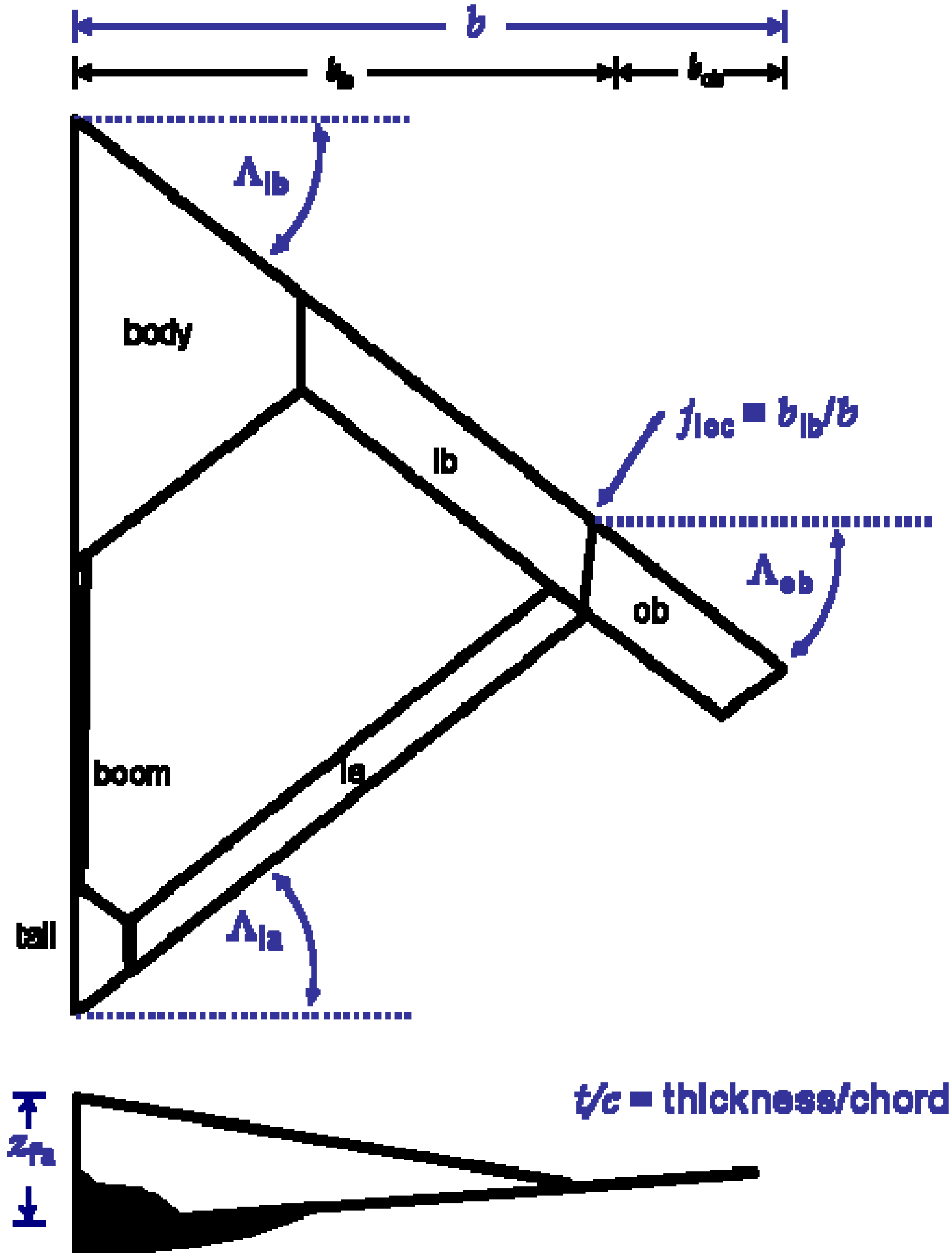


Figure 3 Design Variables for Joined Wing

II. Background

Joined-Wing Design Overview

Joined-wing aircraft are categorized as aircraft having an aft wing joined to a front wing. The front wing root is attached to the fuselage, and the aft wing root is attached atop the tail. Often, the front wing has aft sweep and the aft wing has forward sweep. An outer wing section is usually present due to the joint location, where the front and aft wings meet, being less than the half span. Figure 4 displays an early joined-wing design.

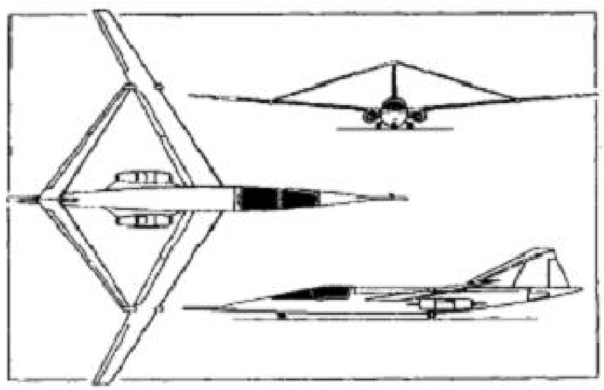


Figure 4 Wolkovich Joined Wing Design

As a result of joining the aft and front wings, each wing can act as a brace or strut in various loading conditions, dependent on the wing geometry and sizing. The aft wing mainly resists the lifting bending moment and acts as a compression strut. This has the effect of reducing the wing structural material required to resist the bending moment caused by lift, but premature buckling is a concern due to axial compression of the aft wing. This relationship may reduce overall weight savings achieved by the wing moment

relief, if the aft wing now requires more structure to resist buckling due to carrying axial loads.

Joined-Wing Design Genesis

The pioneering work in joined-wing design was conducted by **Wolkovich** [7], who holds the 1976 patent for a joined wing aircraft. Later in 1985, Wolkovich [8] published results stemming from finite element and wind tunnel analysis of the joined-wing concept. He detailed several distinct advantages of a joined-wing configuration over a more traditional design, chiefly a lighter, stiffer airframe exhibiting lower induced drag, a high trimmed maximum lift coefficient (C_{Lmax}), and bending moment relief at a very small expense of the span efficiency factor. He also calculated that a joined-wing design could carry 150% of the fuel in conventional designs, due to the additional volume available in the aft wing. This study will investigate the response of a joined-wing design to change in geometric parameters.

Fairchild [9] compared structural weights of a conventional and a joined wing. Both wing types utilized the same airfoil (NACA 23012) with thickness-to-chord ratio (t/c) and structural box size held constant. He showed for aerodynamically equal configurations, the joined-wing design resulted in an approximate 12% reduction in weight over the conventional wing. This study will compare the structural weights of an "optimized" joined-wing and geometric perturbations of that model.

Following Wolkovich, **Smith, Cliff and Stonum** performed calculations and wind tunnel testing on a 1/6th scale joined-wing research aircraft, based on three geometric modifications of the oblique wing test aircraft NASA AD-1. [10, 11] The

demonstrator was analyzed in a Mach 0.8 transport role, at optimum cruise altitude. A principal finding was that of optimum joint location at 60 percent of the fore wing semispan. Wind tunnel data confirmed the design predictions for reduced bending moment on the forward wing, and a span efficiency of greater than one; however, the design displayed unstable stall characteristics, no flight test vehicle was built, and no structural optimization performed. This study will investigate a joined-wing in an ISR role at Mach 0.85 cruise, and optimum joint placement.

Kroo, Gallman and Smith [12] present findings of joined-wing optimization based on a vortex-lattice code to trim for minimum drag, and a finite element code to optimize structural weight. Principal in their results is that weight optimized joined-wing designs were found to have a joint location of 70% of the forward wing half span, and that in each configuration examined the aft-wing carried a negative lift load in order to achieve trimmed flight. This study will investigate the placement of the joint location as a design variable, and its effect on take-off gross weight (TOGW).

Gallman, Smith and Kroo, [13] present a quantitative comparison of joined-wing and conventional aircraft (McDonnell Douglas DC-9) designed for the same medium-range transport mission. Using a LinAir vortex-lattice model for aerodynamic performance estimation, and a beam model for the lifting-surface structure, weight was estimated using Fully Stressed Design (FSD), including a buckling constraint. Three joined-wing aircraft with a joint location near 70% of the wing semispan and two conventional aircraft were compared on the basis of direct operating cost (DOC), gross weight, and cruise drag. When buckling of joined-wing designs is considered, DOCs increase nearly 4%. If reanalyzed today, DOCs may prove cheaper for a joined wing with

lower fuel usage as jet fuel is no longer at $0.70/gallon, and one of the joined-wing designs had a 2.5% cruise drag reduction over the most efficient conventional design. This study uses ACSYNT (ref.3) to conduct the aerodynamic analysis and a non-optimized finite element model to estimate the structural weight of the joined-wing, based on geometric perturbations of the baseline model.

Gallman and Kroo [14]performed a single-configuration, single-mission joined-wing transport study, evaluating minimum weight optimization and FSD methods in terms of weight, stress, direct operating cost (DOC), and computational time. For a medium-range transport mission (2000 nm at M=0.78), a joined-wing with a fixed joint-location (70% of the wing semispan) was optimized for minimum weight and using FSD. Results showed the minimum weight optimization method produced a structure that is 0.9% lighter than the FSD method, and led to a 0.02% DOC savings, but requires more computational time. When the finite element model (FEM) was optimized for minimum weight under gust load conditions, at zero fuel weight, with beam buckling added as a design constraint for the horizontal tail, the structural weight grew 13% and the total weight by 2%. Compared with a conventional design, the joined-wing proved to be 5% more expensive to operate due to the weight increase brought on by considering buckling as a constraint. This study will pave the way for cost analyses for the use of a joined wing as an ISR sensor platform.

Nangia, **Palmer** and **Tilmann** [15] provide an overview of the SensorCraft mission, joined-wing configuration considerations, prediction methods and design aspects. Of note, they point out that “On novel layouts, often the experience is that the complexities ‘defy’ an automatic ‘hands-off’ design process to be used with confidence.”

Their study of a joined-wing SensorCraft designed for cruise at Mach 0.6 shows near elliptic spanwise loadings, with forward swept outboard wing offering an improved spanwise loading consistent with neutral point location. This study will investigate forward swept wing tips and its effect on the aircraft gross weight.

Livne [16] surveyed progress and obstacles in joined-wing design. He determined joined-wing configurations cause complex interactions between aerodynamics and structures, which require multidisciplinary design approach to simultaneously design aerodynamics and structures. This study integrates aerodynamics and structures through the use of an integrated modeling environment.

Recent Local Joined-Wing Collaboration

Blair and **Canfield** [1] originated an integrated design method for joined-wing configurations. Using the Adaptive Modeling Language (AML), Blair developed a geometric model and user interface called Air Vehicles Technology Integration Environment (AVTIE). The model analyzed is the AFRL/AFIT joined-wing configuration (Fig. 2) which can be structurally and aerodynamically analyzed by external software, but requires extensive manual iteration by the user. Prime in their conclusions was that nonlinear structural analysis is imperative to capture with fidelity the large deformations that occur in this joined-wing configuration. This study aims to advance the integrated modeling, providing a framework for further joined-wing research and optimization of structural weight, applied to an advanced joined wing model developed by Boeing.

Roberts [17] validated the assumption that for large span joined wing vehicles, gust loading is the most critical design case. His work focused on ensuring an aerodynamically trimmed aircraft, while optimizing the structure of an aluminum joined-wing to ensure that it is buckling safe. The aircraft considered for analysis was a 210 ft span joined wing, with a 3000 nm Range of Action (RoA) and a 24-hour loiter. This study focuses on the 150 ft wingspan composite Boeing joined-wing model and the reduced mission requirements of 3000 nm RoA and a 12.6-hour loiter.

Sitz [18] conducted a parallel study with Roberts, performing an aeroelastic analysis of an aluminum structural model joined-wing SensorCraft splined to an aerodynamic panel model. Force and pressure distributions were elliptic on the four aerodynamic panels: aft wing, fore wing, joint, and outboard tip with the exception of the fore wing near the joint area. This study uses ACSYNT to perform an empirically based aerodynamic analysis on a Boeing joined-wing SensorCraft design.

Rasmussen [19] continued Roberts work, by geometrically optimizing the AFIT/AFRL composite joined-wing model utilizing six design variables: leading-edge front wing sweep (Λ_{ib}), trailing edge aft wing sweep (Λ_{ia}), leading-edge outboard wing sweep (Λ_{ob}), joint location as a percentage of half span (j_{loc}), vertical offset of the aft-wing root (z_{fa}) and airfoil thickness to chord ratio (t/c). Through 74 different geometric configurations he found non-unique solutions were possible for minimum weight. L/D was fixed for the study at 24 for the purposes of fuel weight calculations. His analysis assumed a fixed half wingspan of 32.25 m and constant chord lengths for fore and aft wing, and a constant t/c for both forward and aft wings along span. This study investigates the geometric optimization of the Boeing joined wing SensorCraft, with the

addition of aerodynamic analysis through ACSYNT, wingspan as an additional variable, and t/c allowed to vary linearly over the span.

SensorCraft Overview

SensorCraft springs from a U.S.A.F. capability requirement for a high-altitude long-endurance (HALE) unmanned air vehicle capable of providing greatly enhanced coverage with radar and other sensors. The SensorCraft mission provides a unique challenge to the aerospace community. Aggressive endurance goals, coupled with space, power and cooling requirements for next-generation ISR sensors pose a conundrum. Several designs and concepts have been proposed to meet this mission need, from traditional scaled Global Hawk-like designs to unconventional joined wing designs. SensorCraft's initial mission requirements were to unite the sensing functionality currently dispersed in several different wide-body aircraft into a single unmanned-aerial vehicle with a minimum 30-hour endurance and a 3000 nm range. This mission was designed to allow world-wide coverage with minimal basing footprint.

Airframe Studies

Figure 5 Visual Comparison of SensorCraft Designs (ref. 20)

Over a period of four years, six differing preliminary designs were forwarded from Boeing, Lockheed-Martin and Northrop-Grumman, along with an even greater

number of conceptual designs. Lucia [20] provides an excellent summary of the genesis of the SensorCraft mission and detailing the developments of the three major design categories; Wing-body-tail, flying wing and joined-wing (fig. 5), design highlights are shown in Table 1.

Laminar flow airfoils are used in all three major configurations, designed to produce favorable pressure gradients up to 70% chord. These airfoils are prone to causing shocks as low as Mach 0.6 due to their relative thickness, and flow separation is possible without the presence of transonic shocks, due to the aggressive nature of the pressure recovery scheme. Lucia [20] warns that “both shocks and flow separation must be considered in an aeroelastic analysis of the SensorCraft configurations.”

Lucia [20] concludes his paper with a challenge to the technical community “to unite and produce an interactive suite of computational tools that couple structural responses to aerodynamic loads in a manner that accurately reflects non-linear behavior.” This study is a step in that direction. He also addresses the need to incorporate static and dynamic stability and control considerations and produce layered solutions from reduced-order methods, to high fidelity solutions to provide cost effective modeling. The present framework can provide the foundation for that approach.

Table 1 Comparison of SensorCraft Designs (data from ref. 20)

Design Parameters	*Lockheed Martin Wing-Body-Tail*	*Northrop Grumman Flying Wing*	*Boeing Joined-Wing (410C)*
TOGW (W_0)	94,500 lbs	125,000 lbs	134,000 lbs
Empty Weight (W_e)	35,300 lbs	55,000 lbs	59,000 lbs
Fuel Weight (W_f)	59,200 lbs	70,000 lbs	75,000 lbs
Empty Wt. Fraction (W_e/W_0)	0.37	0.44	0.44
Fuel Fraction (W_f/W_0)	0.63	0.56	0.56
Wing Span	185 ft	205 ft	165 ft
Length	100 ft	72 ft	103 ft
Payload	6000 lb	7000 lb	9200 lb
Aspect Ratio	20	not given	not given
On-station Loiter	22 hours @ 3000nm	40 hours @ 2000nm	20 hours @ 3000nm
Top of Cruise (ToC) Altitude	55,000 ft	not given	not given
Cruise Mach	0.6	0.65	0.80
Engine	(3) AE3007H Allison Turbofans	(2) unspecified	(2) unspecified
ISR Sensor Incorporation	not addressed	Integrated radar apertures into wing skin	Wing embedded sensors (360-degree field of view)
Unique Challenges	Non-linear aeroelastic response of a very flexible aircraft at high speeds.	Tailless control and stability, residual pitch oscillation (RPO), body freedom flutter.	Flow separation at joints, non-linear aeroelastic response.

Figure 6 gives the Boeing joined-wing model 3-view and size comparison to a B-2 bomber.

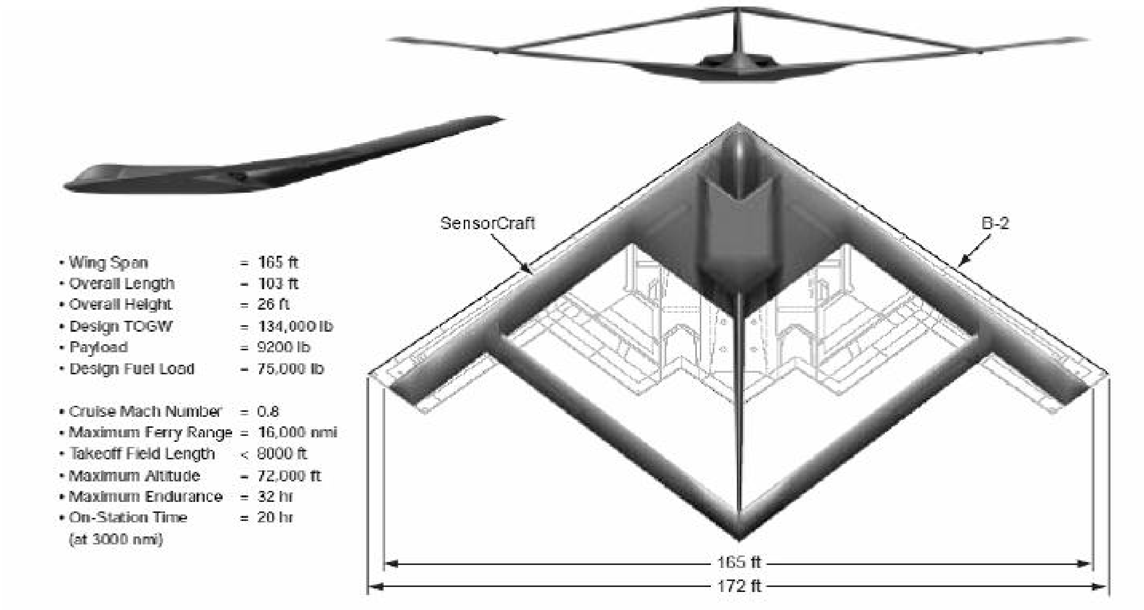


Figure 6 Boeing SensorCraft 3-view and size comparison (Model 410C) (ref. 20)

Boeing AEI Study

The Aerodynamic Efficiency Improvement (AEI) study focused on furthering the aerodynamic and structural design of the Boeing SensorCraft. The final 306-page PowerPoint report was delivered by Boeing to the U.S.A.F. on 17 July, 2006. Highlights are summarized here.

According to Boeing, a joined-wing configuration promises to offer decreased life cycle costs (LCCs) when compared to other potential SensorCraft configurations (e.g., flying wing and conventional wing), based on a utilization rate (UTR) of 360 hours/month and the requirement of a 3000 nm radius of action (RoA). It achieves this savings by reducing squadron size, as only four vehicles are needed versus five for the other designs, due to increased speed and sensor visibility differences of the

joined-wing.

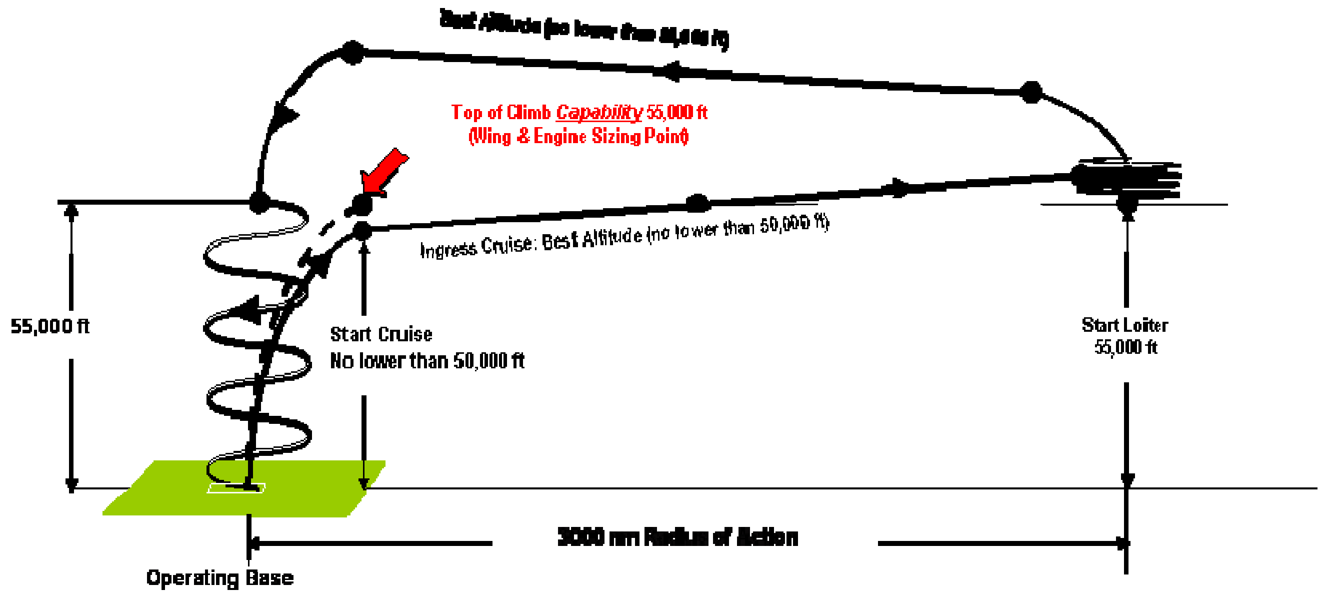


Figure 7 Boeing Joined-Wing SensorCraft Mission (ref. 21)

Mission Profile:

Boeing's modified mission profile (fig. 7) used for performance and parametric sizing analysis and the ACSYNT profile used in this study are shown in Table 2. The mission was based on the AWACS mission (MIL-STD-3013) and includes a fuel reserve factor of 5%. The reduction in loiter time from 24 to 12.6 hours is based on a previous Boeing Life Cycle Cost (LCC) Study (ref. 20) which showed a reduced LCC for an aircraft with a 30 hour overall endurance. According to Boeing, the driving requirement for the sizing studies was the capability of loitering at 55,000 ft at the top of climb (ToC) after a maximum takeoff gross weight (MTOGW) takeoff. Boeing's study used a minimum buffet margin of 0.1 g, and a thrust margin constant with a nominal climb rate of 30 feet per minute for ToC sizing.

Table 2 Mission Profiles for Boeing Analysis and ACSYNT Analysis for Joined-Wing SensorCraft

Mission Segment	Boeing Profile	ACSYNT Profile
Warmup and Taxi	**(0)** 20 minutes at idle power	**(0)** 20 minutes at idle power
Takeoff	**(1)** 0.5 minutes at Mil power	**(1)** 0.5 minutes at Mil power
Initial Climb	**(2)** Climb to 50K ft	**(2)** Climb to 50K ft *
Ingress Cruise	**(3)** 0.85M at 55+K (3000 nm)	**(3)** 0.85M at 55+K (3000 nm)
Pre-Loiter Climb/Descent	**(4)** descent or climb to loiter alt.	*Not modeled*
Loiter	**(5)** 0.8M at 55K (12.6 hrs)	**(4)** 0.8M at 55K (12.6 hrs)
Expendables Drop	**(6)** No drops	*Not modeled*
Post-Loiter Climb/Descent	**(7)** 8K climb to cruise alt	**(5)** 8K climb to cruise alt
Egress Cruise	**(8)** 0.85M at 55+K (3000 nm)	**(6)** 0.85M at 55+K (3000 nm)
Final Descent	**(9)**	*Descent credit of 80 nm*
Reserve Loiter	**(10)** 20 minutes at SL	**(7)** 20 minutes at SL

** Due to ACSYNT climb limitations the climb segment is actually broken up into 3 different CLIMB portions in the ACSYNT mission input.*

Boeing claims best cruise fuel mileage occurs in climbing cruise at 85% power setting with a start-cruise altitude (at ToC weight) of approximately 53,500 ft. For a RoA greater than 2,000 nm the best cruise altitude at start-loiter weight is higher than the 55,000 ft loiter altitude, and Boeing includes a small descent segment prior to loiter. After loitering the best cruise altitude at end-loiter weight is much higher than the 55,000 ft loiter altitude, so an approximate 8000 ft climb segment is introduced. The reserve loiter duration is less than the 30 minutes specified in the Mil Standard AWACS mission, but adequate due to the high final cruise altitude and high vehicle L/D allowing easier reach of a divert airfield. Some of the theoretical issues the Boeing team contended with were that the joined wing optimum loading is not unique, and shifting of a constant load from rear wing to front should have an effect only on pitching moment only, with no effect on induced drag.

Baseline Configuration (Model 410E)

The baseline planform designed for the AEI study (1076-410E) is a modification of the Point-of-Departure layout (1076-410D). The main wing has a span of 150 ft, a mean aerodynamic chord (mac) of 161.287 inches (13.44 ft), 1980 ft^2 forewing-only reference area, and Taper Ratio (λ) = 0.61. This planform was developed for a mission with a top of climb (ToC) at 55,000 ft, cruising at Mach 0.85, at 112,000 lb, with a C_L of 0.58.

The initial *AEI Performance Objectives* corresponded to an earlier SensorCraft predating the AEI study and having a wing span of 172 feet. The Point-of-Departure configuration given to the AEI Team (Model 410E) had a wing-span of only 150 feet, and correspondingly lower L/D target, 21 versus the original 24. In addition, the design cruise Mach number for the 410E configuration was increased to 0.85M. Although stated as objectives of the AEI program, descent L/D and lateral stability were not studied.

Airfoil creation method

The critical station, a function of local t/c and sectional C_L, was determined to be at the 54% semi-span location for an elliptical spanload. Conditions at this station were transformed using simple-sweep theory. At cruise conditions, the critical station 3D sectional lift coefficient is about 0.66. Using simple-sweep theory, the resulting 2D conditions are $Mach = 0.67 = 0.85\cos(38)$ and $C_l = 1.06 = 0.66 \big/ (\cos(38))^2$. The optimal airfoil was then created using an inverse-design process based on Drela's MSES CFD code, a coupled Euler-BL method using a streamline grid. Then 2D pressure distributions from MSES were analyzed by XTRANS to establish the extent of the laminar run on both upper and lower surfaces. The airfoil was tweaked to enhance

laminar flow and the 2D section was transformed back to 3D, and incorporated into the 3D wing OML definition.

Simple-sweep theory broke down due to two primary reasons related to the SensorCraft layout. The first is the aggressive trailing-edge break (aft strake or yehudi) of the main wing, characterized by sweep angles of +/- 35 degrees. This trailing edge break caused the shock system of the main wing to un-sweep, thus making the shock much stronger and producing large wave drag. Flow also separates at the base of the shock, which in turn increases the profile drag. This phenomenon affects the whole configuration from about 65% semi-span of the main wing inward.

The second break-down of simple-sweep theory is related to the main-strut joint geometry, which induces sufficient three-dimensional flow in its vicinity. Simple-sweep theory worked well on the mid-region of the strut, due to its relatively small yehudi and airfoils that are only lightly loaded by design.

Improving Lift-to-Drag (L/D) Ratio

An initial goal of the AEI study was to design a joined-wing configuration that achieves the L/D performance goals without a lifting strut, in order to reduce the buckling tendency of the strut in compression and provide a more conservative estimate of the L/D performance of the A/C in trim. Early assessments of the aircraft’s L/D only yielded a value of 13.6. Two parallel efforts were then used to increase the baseline SensorCraft 410E toward the SensorCraft goal L/D of 21:

(1) The Multi-Disciplinary Optimization (MDOPT) system was used to optimize the wing-design planform to meet purely aerodynamic performance criteria, and

(2) aerodynamic performance of the main wing was improved by applying Professor Jameson's SYN107 Transonic Wing Optimization code (Stanford University) to a wing/pseudo-body configuration, and Boeing's Divergent Trailing Edge (DTE) Technology was inserted into the SYN107 Optimized wing (ref. 21).

Multi-Disciplinary Optimization (MDOPT)

The main components of the MDOPT system (ref. 22) and process steps (fig. 8) in an optimization are: (1) input geometry, (2) create surface grids/lofts, (3) define design variables, (4) create design of experiments (DOE), which perturbs geometry and runs the discipline analysis codes, (5) create interpolated response surfaces (IRS) for the constraints and objective functions, (6) perform optimization on IRS models, (7) and output final optimum geometry and design vector.

Two MDOPT runs were performed: The first run used 29 wing design variables, 3 thickness and 3 camber variables at each of 4 span stations, plus the 5 twist design variables, and 6 design variables for the aft wing. The second run expanded the variable space, with 35 wing design variables, 3 thickness and 3 camber variables at each of 5 span stations, plus the 5 twist design variables, and 13 design variables on the aft wing, 1 thickness and 2 camber at 4 wing span stations, twist at 4 stations. The MDOPT process resulted in a much cleaner joint design, and achieved an efficiency 1.8 percent less than the L/D design goal of 21.

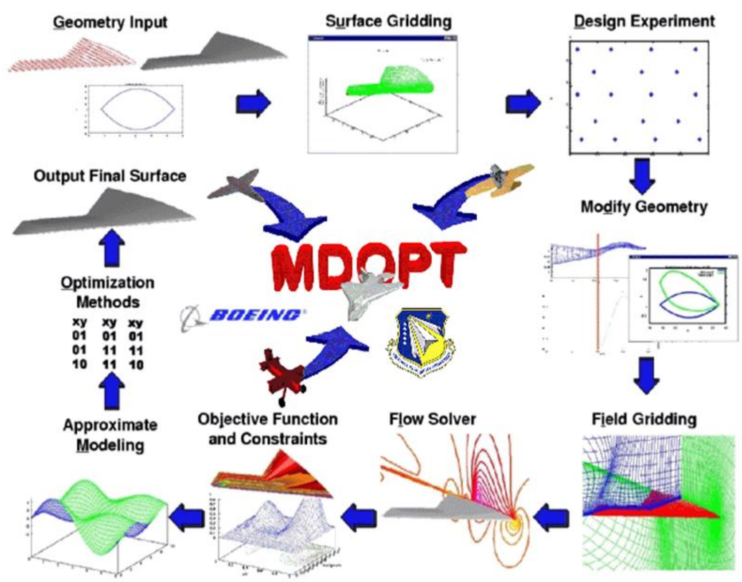


Figure 8 Multi-Disciplinary Optimization System (ref. 21)

Boeing Finite Element Model (FEM)

The delivered finite element model (FEM) shown in Figure 9 is based on the new configuration 410E Outer Mold Lines (OMLs) defined by the AEI aero group The model's mesh size is about 5 inch, considered sufficiently fine to capture local buckling effects and provide good stress results. The structure's composition is IM7/8552 graphite

and BMS 8-139 fiberglass. Sandwich construction was used extensively for its inherent buckling stability. Fiberglass was used in the leading edge of the forward wing and trailing edge structure of the aft wing that need to be radio transparent. In terms of size, the model has: 81,550 nodes, 118,915 elements, and 490,000 Degrees of Freedom (DOF). Structural elements were not sized to handle design loads, but were approximately sized based on experience with prior configurations. Structural mass was modeled largely with material density with concentrated mass items represented by nonstructural mass elements.

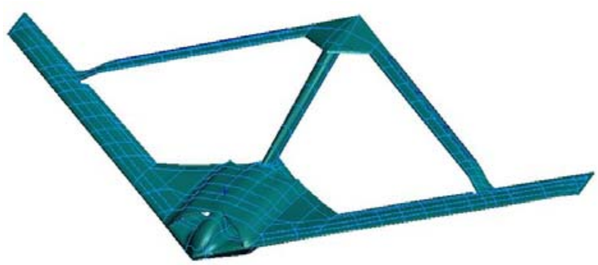


Figure 9 Boeing Finite Element Model (FEM) Model 410E

Aerodynamic Analysis Used

Boeing's aerodynamic analysis consisted of a 2459-box doublet lattice aerodynamic model, using a flat lifting surface representation of the actual geometry for both static and dynamic aeroelastic analyses.

Summary of Boeing Findings of Joined Wing Benefits

A joined wing SensorCraft offers the capacity for enhanced sensor integration, structural efficiency, redundant controls, and aerodynamic rewards. The large surfaces enable structurally-integrated low-band (UHF) apertures with a 360-degree field-of-view.

Structural deflections are reduced over a conventional wing of the same span, and there is a promise of efficient load-sharing between wings. Multiple aerodynamic control surfaces are possible effective about all axes providing control system redundancy, and the moderately swept wings provide high subsonic speed capability, plus the non-planar lifting system should provide induced drag benefits.

Table 3 JW Model 410E FEM Empty Weight Breakdown

Grouping	Boeing	Standard
Structure	22851	26709
Propulsion	11977	11977
Nose Gear*	458	*
Main Gear*	3400	*
APU	864	864
Mission Package	8861	8861
Flight Controls	1199	1199
Electrical	1064	1064
Total Empty	**50674**	**50674**

* Landing Gear weight is usually rolled up into *Structural weight*, shown in the second column in standard fashion.

Structural Weights Summary

Boeing's claim of a reasonable similarity between the baseline (410D) and optimized FEM model structural weights (410E) appears invalid, because the landing gear weight (3858 lbs) is not incorporated into the structural weight in the optimized model, and there is no 10% reserve for fittings and joints calculated into the baseline model. Table 4 presents a standardized weight comparison of the model data for baseline (Model 410D) and optimized (Model 410E) model after one sizing iteration through the MDOPT system.

Table 4 Boeing SensorCraft Structural Weight Comparison (Baseline vs. Optimized)

Component	Baseline *Model 410D*	Optimized *Model 410E*	(Corrected) Baseline *Model 410D*	(Corrected) Optimized *Model 410E*
Wing (total)	12144	11003	12144	11003
Aft Wing	-	3351	3698	3351
Fwd Wing	-	7652	8446	7652
Horiz. Tail	0	762	0	762
Vert. Tail	1245	1238	1245	1238
Body (total)	7326	9264	7326	9264
Fuselage	5839	-	5839	7777
Air Induction	621	-	621	621
Nacelle	866	-	866	866
Landing Gear	3857	-	3857	3857
Structure (total)	24572	22267	**24572**	**26124**
Reserve (10%)	-	2269	2457	2612
Structure (total)	24572	24536	**27029**	**28736**

In the optimized model, the forward wing weight accounts for 69.55% of the total wing weight, and to allow similar comparisons for the baseline model the same weighting factor was used to determine the approximate weights of the forward and aft wing, as those breakdowns were not given. The 10% reserve is to account for joints, fittings, access panels and other details that are not explicitly defined in the FEM. This table shows that the optimized model actually experienced weight growth of 6.3% over the baseline model.

AEI Study Results

Boeing claims total aerodynamic efficiency achieved was 1.8 percent less than the goal at the design point. Their revised goal for cruise L/D for the 410E model was 21,

which means they achieved an L/D of 20.6. The stated intent at the onset of the AEI was to produce a configuration with a zero-lifting aft wing. At the conclusion of the study the decision was made to carry some positive load on the inboard aft wing.

Boeing's results showed the design is elastically stable, and the nonlinear large-deflection analysis showed a positive margin on all components with respect to buckling. They recommended a further analysis to investigate the issue of follower forces if wing deflections are large enough to create significant differences when not using follower forces. Boeing data also showed the design to be aerodynamically stable, with the detailed flutter analyses revealing a 2 degree AOA margin from the high speed cruise point to severe pitching moment non-linearity onset. As predicted by Roberts [17], Boeing also found that gust loads will size the aircraft, as they produced the largest loads on the largest number of structural elements. As a final note the structural model produced is not structurally optimized. The structural optimization process only just began toward the end of the contract.

Boeing Joined-Wing SensorCraft (Model 410E)

The latest contract delivery of joined-wing SensorCraft data produced the specifications and CAD model (fig. 10) for Model 410E. From this model and other Boeing data (ref. 21) the ModelCenter joined-wing model was constructed.

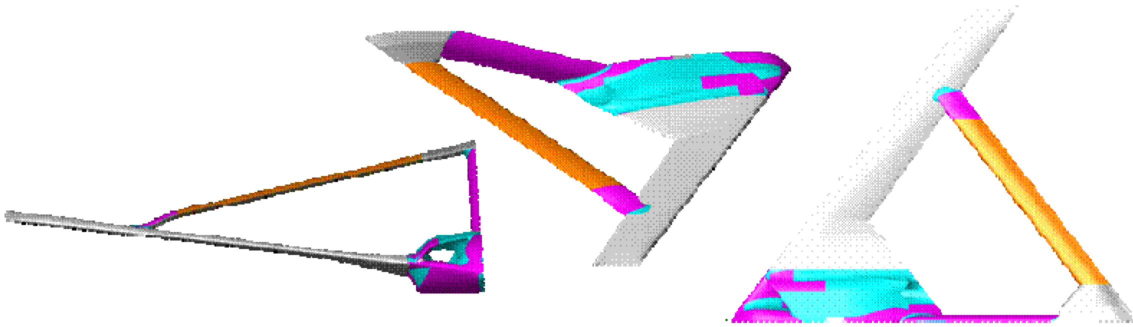


Figure 10 CAD Model of 410E

The Boeing joined-wing SensorCraft (Model 410E) is defined by the following characteristics (table 5); Model 410C, an earlier model and the AFIT joined wing concept (fig. 2) are given for comparison.

Table 5 Model Parameter Comparison

Parameter	***AFIT Joined Wing (baseline) (ref. 19)***	***Boeing Sensor Craft Model410C (baseline)***	***Boeing Sensor Craft Model410E(optimized)***
Wing span (b)	225 ft	165 ft	150 ft
Tail Height (z_{fa})	23.13 ft	14.28 ft	16.13 ft
Joint Location (j_{loc})	0.7647	0.7176	0.7117
Thickness/Chord (t/c)	0.20	varies with span	0.08/0.14 fore/aft(avg.)
Inboard Sweep (Λ_{ib})	30 degrees	38 degrees	38 degrees
Tail Sweep (Λ_{ia})	30 degrees	38 degrees	38 degrees
Outboard Sweep (Λ_{ob})	30 degrees	38 degrees	38 degrees
Length Overall (l_{oa})	-	103 ft	97.36 ft
Airfoil	LRN-1015	Custom	Custom
Forward Chord (c_f)	8.36 ft	varies with span	c_r = 16.4 ft, λ = 0.61
Aft Chord (c_a)	8.36 ft	varies with span	c_r = 14.3 ft, λ = 0.97
Height Overall (h_{oa})	-	26 ft	19.13 ft
Aspect Ratio Eff.(AR_e)	15.41	7.54	8.17
S_{ref} (wing)	3026.2 ft^2	2928.3 ft^2	2755.5ft^2

Both the Boeing Models and the AFIT SensorCraft employ a conformal load-bearing antenna structure (CLAS) embedded in the front and aft wings inboard of the joint location. The Boeing Model also has CLAS outboard of the joint. This load-bearing

antenna structure is a composite sandwich of graphite/epoxy, carbon honeycomb foam core, and fiberglass as shown in Figure 11.

Figure 11 Conformal Load-bearing Array Structure (CLAS)

The graphite/epoxy layers can support loads, which aids in minimizing wing structural weight, potentially providing a significant weight savings over conventional aircraft construction. Both the honeycomb core and fiberglass provide negligible structural strength, but the fiberglass protects against external environmental effects and is an electromagnetically clear material though which the radar antenna can freely receive and transmit.

III. Methodology

Overview

Today's aircraft systems are increasingly complex multidisciplinary systems. Multi-disciplinary Optimization (MDO) or concurrent engineering (CE) are required as aircraft grow in complexity, and aircraft engineers can become more specialized and isolated in their distinct disciplines. Bringing their corporate knowledge and expertise together in one location is critical to ensure a successful, balanced design. Along with traditional design disciplines, manufacturing, support and cost considerations should also be examined.

Multi-disciplinary system design is a computationally intensive process combining individual discipline analysis with total design-space search and decision making. Previous practice had been "stovepiped" disciplines performing independent optimizations with limited direct interaction or communication with other disciplines. Therefore the balancing of discipline analysis and creating "joint" data – shared throughout the various disciplines becomes a non-trivial task, which can be eased by the use of Integration Environments, such as ModelCenter.

The more one can front-load the design integration, pushing MDO considerations into early conceptual design phases, the more impact the integration can have on the time, cost and quality of the designed product, as integration only gets more difficult and costlier in the preliminary and detailed design phases.

In the aircraft conceptual design process, there are five major design areas requiring extensive time and effort: aircraft layout (geometry), aerodynamics, weights

(including payload), propulsion, and performance. For each discipline a design process is followed including a large and complex series of decisions and calculations to determine the design parameters of the aircraft. After initial parameters have been determined, the design is compared to any specified requirements, appropriate changes are made, and then another series of decisions and calculations is completed to refine the design. This cycle is repeated until the aircraft design created meets the specified requirements.

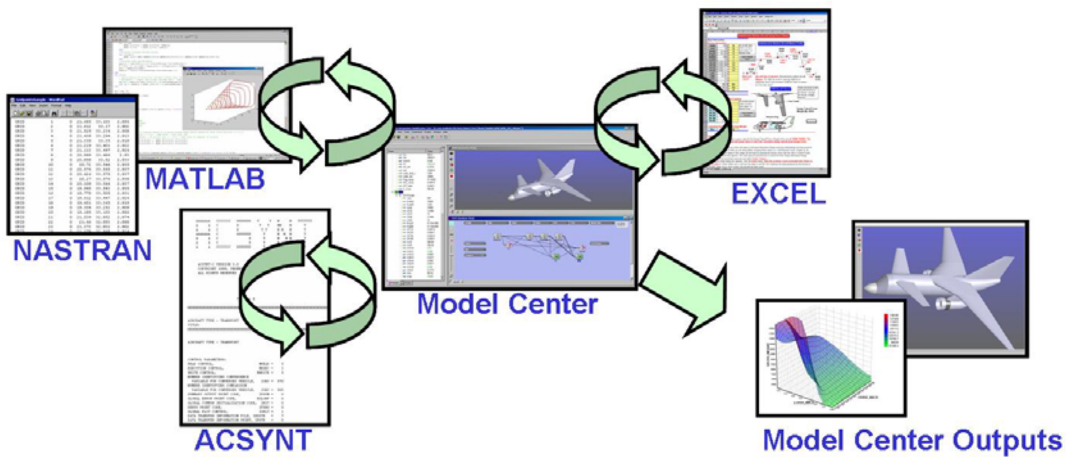


Figure 12 Simplified Integrated Sizing Method

All of these tasks were accomplished in the integration environment ModelCenter. (fig. 12) Three models were constructed (fig. 13) and analyzed in increasing fidelity and depth; (1) an S-3 Viking, (2) Raymer's ASW aircraft, and (3) Boeing's Joined Wing SensorCraft.

(1) S-3 Viking (2) Raymer's ASW Aircraft (3) Boeing Joined-Wing

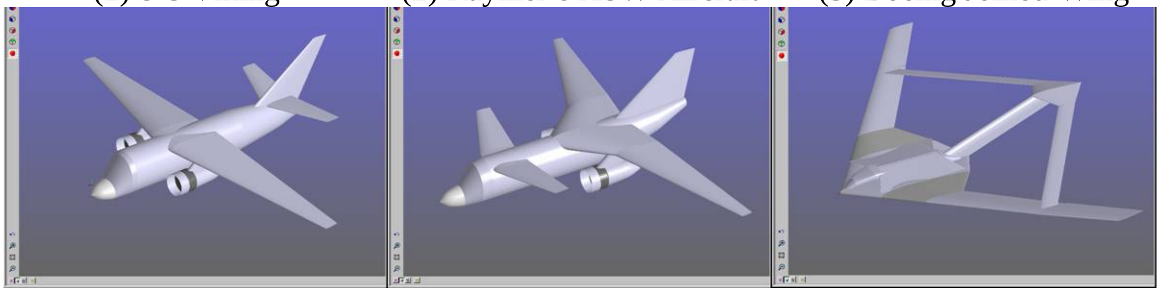


Figure 13 ModelCenter 3-D Geometry

Models were sized by differing methods, increasing in complexity and dependence on analytical vice historical methods. For the first two models, Raymer's (ref. 2) methods for initial (chapter three) and refined sizing (chapter six) were followed, along with approximate and group weight estimations (chapter fifteen). Finally an ACSYNT model was tied into ModelCenter and the results were compared with previous lower order routines and in the case of the S-3, actual flight test data from the S-3 NATOPS. (ref. 4)

The Joined-Wing model (410E) was sized based on the initial and refined methods for comparison with actual Boeing data and the ACSYNT model was created and calibrated to yield structural weights agreeing with the initial Boeing FEM data. Once calibrated, the Joined Wing model could be perturbed to investigate various responses to the design variables. Also the FEM of the joined-wing was wrapped in ModelCenter to provide structural weights from NASTRAN in lieu of ACSYNT structural data.

Tools Used

ModelCenter

Phoenix Integration's ModelCenter provides the integration environment to manage integrated processes, application execution, and data flows.(fig. 14) Widely used in industry and government it allows rapid analysis and design space exploration with graphic display of results, in many differing forms.

One of the main strengths of the program is the ability to "wrap" files and programs, including black box legacy codes to permit remote program or file execution from within the ModelCenter environment, and visual interconnection of data between codes and programs. Various scripting languages are supported as well as built-in file wrappers for Excel, MATLAB and other often used engineering applications. Several toolkits are included which aid in model exploration, the performance of parametric and optimization studies, design of experiments (DoE), Response Surface Methodology (RSM) and the ability to save, track and compare design histories.

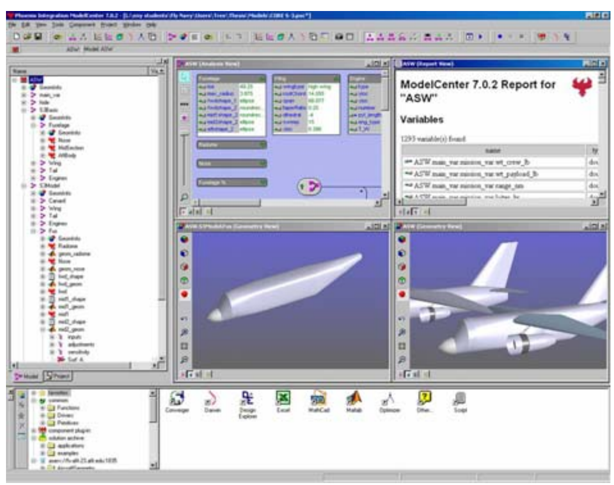


Figure 14 ModelCenter Integration Environment

Model Coordinate System

The model coordinate system (fig. 15) chosen is traditional from a design perspective. The X coordinate is measured as positive from the aircraft nose to the tail, the Y coordinate is measured as positive out the right wing from aircraft centerline and the Z coordinate is measured as positive from the longitudinal center toward the top of the aircraft. In order to display ModelCenter models in such a coordinate system one must make the following adjustments to the top level Model.GeomInfo.Orientation file.

Variable: Rotate_X = 270

Variable: Rotate_Z = 90

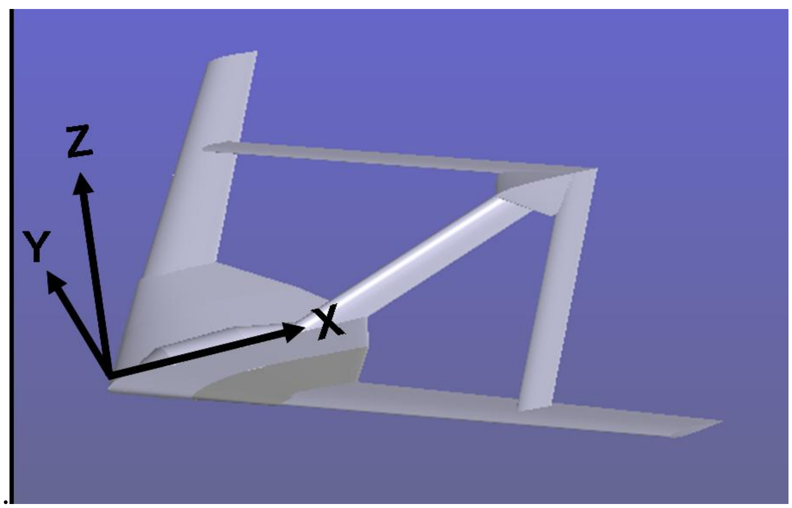


Figure 15 Model Coordinate System

MATLAB

Model Center comes with several components preloaded, geometry primitives such as cubes and spheres, as well as some parametrically derived shapes pertinent to aerospace structures: wings (single and multi-section), and fuselage components (nose, midsection, and aft, shown in figure 16.) These predefined aircraft components however have some significant limitations.

(1) Wing components - do not have a calculated volume, or wetted area, although they do have a plan area. The wing components are built on a baseline airfoil, but that airfoil is not modifiable, without rewriting the java code and repackaging as a .jar file. Multi-section wings offer some flexibility in creating more non-traditional wing forms, but do not support dihedral or anhedral. Several individual wing components can be tied together to create a multi-section wing that can employ dihedral. As a lesson learned, the "type" of wing is related to whether it is used as a vertical tail (type = 4) or wing/horizontal tail (type = 6). This allows proper calculation of Aspect Ratio (AR) and Planform Area with the span for each component defined as the entire span.

(2) Fuselage components – also do not have a calculated volume or wetted area, and can not model shapes other than circular or elliptical in circumference. Although they can be tapered, they cannot be offset in the y or z directions, preventing upsweep commonly seen in fore and aft sections.

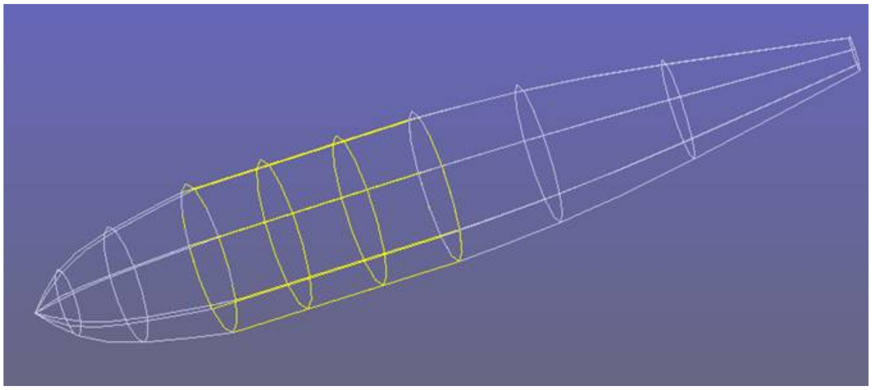


Figure 16 Fuselage Wireview Rendered in ModelCenter (Nose, Midsection and Aft)

Without a calculation of the wetted areas and the volumes, the geometry does not yield much for use in aerodynamic calculations, and the fuselage shapes will be less than adequate for unconventionally shaped fuselage designs.

Therefore several MATLAB codes were written to (1) allow the calculation of wing volume and surface areas (Swet), incorporating airfoil MAT files, and based on ref. [2] equations, and (2) create super-elliptical fuselage shapes allowing features such as square, rectangular, and rounded rectangular cross sections, advanced tapering and calculation of areas and volumes. In addition, scripts written in VBScript were used to convert MATLAB data into textual strings interpretable by Model Center in order to tie the geometric parameters to Non-Uniform Rational B-Spline (NURBS) 3-D graphic models.

Super-Elliptical Fuselage Shapes

Many aerodynamic bodies are not axisymmetric and often an upsweep or downsweep is desired in fuselage shapes. Super-ellipses provide the ability to produce a wide variation of shapes, from circular or elliptical cross sections, to rectangular or chine-shaped sections.

A MATLAB code (App. C) was written to allow super-elliptical fuselage cross sections (fig. 17), based on the Cartesian equation for a super-ellipse given as:

$\left|\frac{x}{a}\right|^{p} + \left|\frac{y}{b}\right|^{q} = 1$ or described parametrically as: $x = a\cos^{2/p} t$ and $y = b\cos^{2/q} t$, where constants *a* and *b* correspond to the maximum half-breadth (the maximum width of the body) and the upper or lower centerlines respectively, and *p* and *q* are exponents to shape

the ellipse. If $a = b$ then the resulting shape will be symmetric in both x and y axes, and when $p = q$ the resulting shapes are similar to the samples indicated in fig. 17.

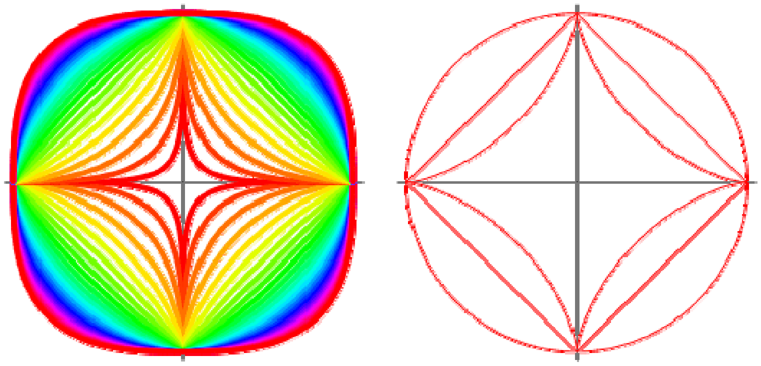


Figure 17 Sample of Super-Elliptical Cross Sections (ref. 28)

The below diagram (fig. 18) illustrates the possible cross-section possibilities using a super-ellipse with $a = b$ and p and q varying from 1 to 4. At very large positive values of p and q the cross sectional shape approaches a rectangular or square shape.

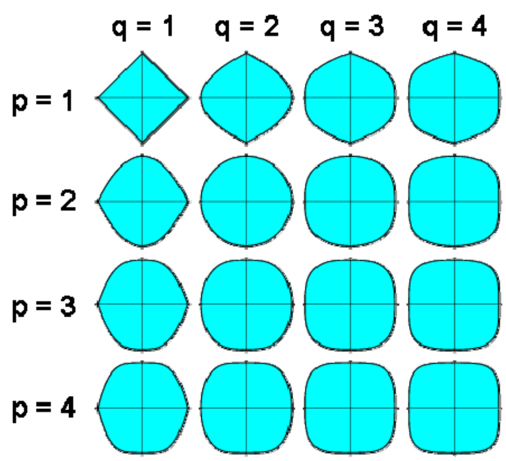


Figure 18 Super Elliptical Cross Sections for p and q Varied from 1 to 4. (ref. 28)

The MATLAB code also allows a vertical (z-axis) and horizontal offset (y-axis) of the fuselage section, enabling shapes that are not axisymmetric as shown in figures 19 and 20.

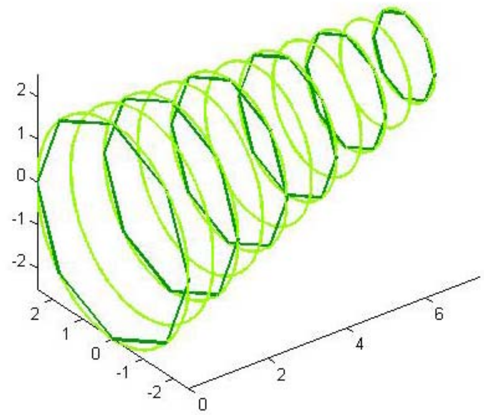


Figure 19 MATLAB Display of Non-Axisymetric S-3 Model Aft Fuselage

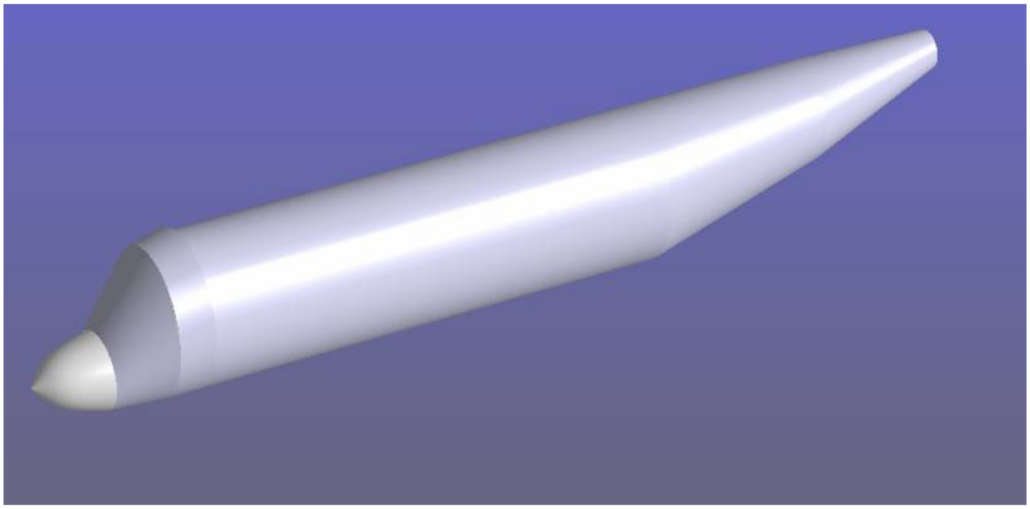


Figure 20 S-3 Cylindrical Non-Axisymmetric Fuselage

Circle-to-square shape adapters and other interpolated cross-sectional shapes can be constructed and used with this code (figs. 21 and 22). Chapter 7 of reference 2,

discusses in detail the subject of lofting, connecting splines and the utility of designing toward flat wrapped fuselage lofts.

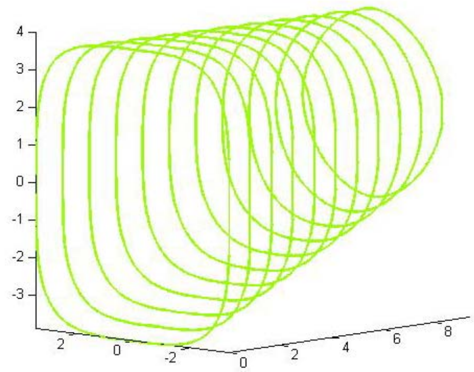


Figure 21 Square-to-Circle Shape Adapter

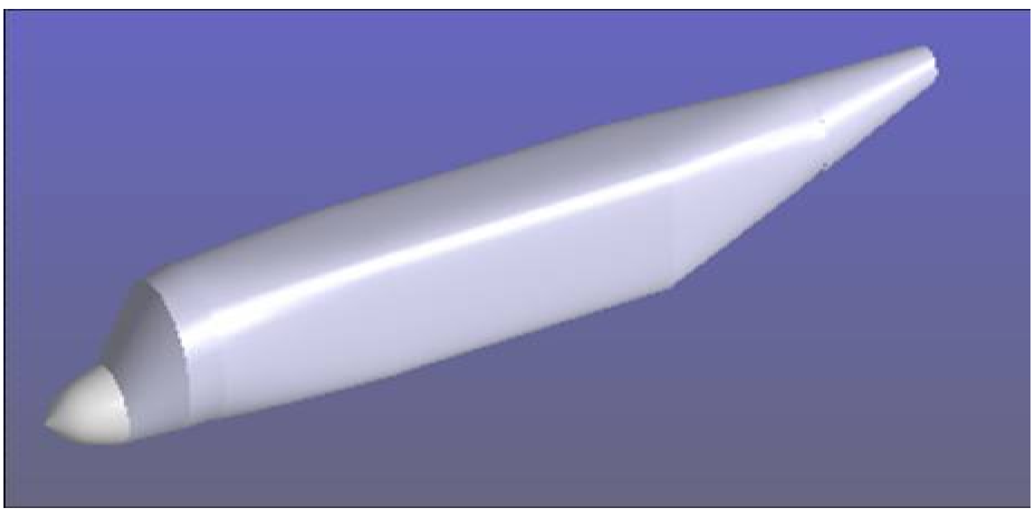


Figure 22 S-3 Rounded Rectangle Non-Axisymmetric Fuselage

Perimeters and areas were calculated for each cross-section and numerically integrated to produce wetted surface areas and volumes of desired shapes (App. C and D).

AirCraft SYNthesis (ACSYNT)

Aircraft Synthesis (ACSYNT), a FORTRAN-based preliminary/conceptual design code, was developed by NASA Ames Research Center and has been widely used to perform aerodynamic and performance analyses on aircraft configurations, based on semi-empirical formulas (ref. 3). It is a useful tool for performing rapid analysis with very short runtimes, on the order of seconds. The downside is that the ACSYNT learning curve is quite steep, several modules are error prone and the current user manual (ref. 3) is lacking in clarity and completeness, causing the problem setup and formulation time to be extensive. A better manual exists online It is now used under the name ACS but many of the names and functions are still the same and the online manual has some of the missing figures and pictures which enable comprehension of the program. It is available online in html format, (ref. 24). **Parker** (ref. 23) details many of the undocumented errors that plague ACSYNT especially in the TRAJECTORY module and gives four examples of ACYSNT, including an A-10 ACSYNT model, that can be helpful in troubleshooting.

The version of ACSYNT used in this study was v3.0, which was a rewrite of the FORTRAN code into C supplied by Phoenix Integration. One problematic feature with the C code is the errors are often generic and not traceable, as there is no specific module or offending line of code displayed.

ACSYNT is modular in organization, with each module performing different analysis functions or analyzing separate aircraft design disciplines. The main modules are Geometry, Trajectory, Aerodynamics, Propulsion and Weights

These modules and others such as takeoff/landing and economics can each be called separately. ACSYNT is run in MS_DOS and commands to run modules select output data, and enter namelist data (for example, the wing namelist is $WING followed by parameter names and values and terminated with $END) are contained in the input file (filename.IN). For complete listing of modules and their use see refs. 3 and 25. Custom modules can be even be added; **O'donnell** (ref. 5) uses a Navy-specific module in ACSYNT for his analysis of a carrier based ASW Aircraft modified for STOL to ensure Navy specific requirements are met for catapult launches and arrested landings.

Primary ACSYNT Modules

Geometry Module – This module calculates surface areas and volumes for input component geometry based on primitive geometry calculations and the totals can be shaped by weighting factors (SWFACT and others) to arrive at a more exact S_{wet} and or volume calculation. The fuselage is represented as a cone-shaped nose connected to a constant radius mid-section and a cone-shaped tail section. The length of the sections and their fineness ratio (length/maximum diameter) is entered via the $FUS namelist.

An ACSYNT limitation of a fixed number of namelist inputs hinders the simulation of designs with multiple fuselages or bi-plane or staggered wings. Only one $WING, $STRAKE, $HTAIL, $VTAIL and $FUS namelist can be included in the geometry input file. This restricts the ability to conveniently model joined-wings.

Wing wetted area geometries (horizontal tail, vertical tail, wings, and canard) are calculated by the following formula – printed incorrectly in both the ACSYNT manual and the ACS website.

$$S_{wet} = \left(SWFACT \bullet S_{ref} \bullet 2\right)\left[(1 + (t/c_{avg})\left(1 - \frac{d_{body}}{b_{surface}}\right)\left(1 + \left(\frac{d_{body}}{b_{surface}}\right)\left(\frac{\lambda - 1}{\lambda + 1}\right)\right)\right] \tag{1}$$

where:

λ	= Taper ratio, (tip chord/root chord)
$b_{surface}$	= Span of the surface
SWFACT	= Wetted area scaling factor, used to compensate for simplistic geometry rendering if actual wetted area known.
t/c	= thickness to chord ratio
$s_{planform}$	= platform area
d_{body}	= body diameter

Equation (1) is more accurate when the wing approximates a flat plate (t/c = 0) and loses fidelity as t/c approaches 0.25.

For cylindrical shapes (Engine nacelles or fuselage) S_{wet}.is determined as follows.

$$S_{wet} = \pi \sum \left(\left(d_i + d_{i-1}\right) \sqrt{\left(\frac{\left(d_i - d_{i-1}\right)^2}{4} + \left(x_i - x_{i-1}\right)^2 \right)} \right) \tag{2}$$

where:

d_i = diameter of body at x_i location along fuselage
x_i = location along fuselage body length

Volume calculations are conducted in a similar manner for bodies and surfaces via equations (3) and (4).

$$V_{body} = \frac{\pi}{8} \sum \left(\left((d_i)^2 + (d_{i-1})^2 \right) \left(x_i - x_{i-1} \right) \right) \tag{3}$$

$$V_{surface} = \frac{0.7}{12} \left(t/c \right)_{root} (b) (c_{root})^2 \left[\left(4\lambda^2 + \lambda + 1\right) + \left(1 - \frac{d_{body}}{b_{surface}}\right)\left(1 + \left(\frac{d_{body}}{b_{surface}}\right)\left(\frac{\lambda - 1}{\lambda + 1}\right)\right)\left(3\lambda^2 + 2\lambda + 1\right) \right] \tag{4}$$

Trajectory Module - This module determines the flight path of the aircraft for a specified mission profile. It employs the Breguet Range and Endurance equations with each phase being broken up into five smaller legs. This module is the most susceptible to producing run-time errors for apparently good mission profiles. One quick check is to ensure the number preceding the mission section matches the number of mission legs.

Aerodynamics Module – This module, based on compressible wing theory, computes the coefficients of lift, minimum and induced drag and pitching moment for wings and wing-body combinations with or without a horizontal tail.

Airfoil shapes are restricted to five different classes of airfoil (ALELJ variable name): (1) sharp and near-sharp (2) 230XX and 00XX (3) 6-series airfoils (4) Whitcomb supercritical airfoil and (5) leading edge radius-to-chord ratio specified.

Zero-lift drag (CD_0) can be calculated directly based on input geometry data (with $ADRAG namelist set ICDO = 0) or can be explicitly specified for an array of user specified Mach numbers in using the CDONPUT, and SMNCDO fields.
Aerodynamic characteristics are input via the $ACHAR namelist, allowing the input of an array of C_{L0} and C_{m0} versus Mach values for the body, wing and canard. Lift curve slopes and the drag polar shape can be modified as required by the altering of FVCAM and FLDM values in the $ATRIM namelist. One important variable used in the joined-wing portion of this study is SFWF, the laminar-turbulent skin friction weighting factor, which determines the coefficient of friction to be applied in form drag calculations. This is a critical point, because to achieve high L/Ds, there is a need for laminar flow airfoils.

Trimming should be able to be performed by a canard or a tail as ref. 3 intimates, "The aircraft can be trimmed through the use of the horizontal tail, wing flaps or canard" but ref. 3 also states "For canard aircraft trimming is done with the wing flap." This contradiction caused several problems with the trimming of the canarded ASW aircraft (model 2).

Propulsion Module– This module utilizes performance data from one of five engines (one turbojet and four turbofans) as selected by the user to size the aircraft's power plant and calculate its performance. Ref 23 and 25 contain a full table of default engine values for the various designs, here is a summary.

Table 6 ACSYNT Default Engine Data (ref. 23)

Variable	(1) J-85	(2) TF-30	(3) JT-8D	(4) JY-9D	(5) CF-6	(6) Generic (TF-34)
Type Engine	Turbojet	Turbofan	Turbofan	Turbofan	Turbofan	Turbofan
Bypass Ratio	0.0	0.73	1.03	8.2	4.4	6.23
Thrust, no AB	2720	14560	14500	50000	50280	9300
Thrust w/ AB	4080	25100	0	0	0	0
Weight	608	3790	3218	8874	9767	1421

Any of the above engines can also be modified or scaled using the Engine Scaling Factor (variable ESF). Users can also enter engine parameters from specific engines via the $LEWIS namelist.

Weights Module – This module calculates the initial and final weights of the aircraft based on established equations for wing and fuselage sizing. It also allows the initial values for major aircraft components, and known component subsystem weights to

be specified, and slopes for technology or scaling factors to be applied when trying to model a known system.

As an example, ACSYNT's wing weight calculation equation from ref. 26 is given below.

$$W_{wing} = K_{scl} \left\{ 0.0202 \left[\frac{W_{TO} n AR}{(1+\lambda)} \right]^{0.5} (Sw)^{0.7} \left[\frac{5(2W_{TO} - 2\, W_{wingfuel})}{2\, W_{TO}\, (4(t/c)_{root} + (t/c)_{tip}} \right]^{0.4} \frac{1}{\cos(\Lambda_{c/4})} \right\} \quad (5)$$

ACSYNT Operation

The control module calls each module as required and the called module performs its analysis, applies its constraints to the aircraft configuration and updates global variables as required. Modules are called multiple times until they converge on a solution of an aircraft configuration that can perform the specified mission, or exceed constraints given resulting in nonconvergence.

ACSYNT flies the aircraft through the mission several times and on each trip through it refines the estimated fuel value required to fly the mission. This fuel adjustment alters the vehicle takeoff gross weight (TOGW) which in turn affects overall structural and required fuel weight. This process continues until convergence occurs, defined as estimated weight agreement with current design weight within the tolerance specified, or the solution is unobtainable and the design does not converge in the specified interval.

General Geometry Generator (GGG)

A Boeing tool under development, the General Geometry Generator (GGG) version 2.0, is a Python-based code which allows the generation and manipulation of basic geometrical and aircraft specific shapes in order to produce “water-tight” outer mold line (OML) geometry which can then be used in the creation of Computational Fluid Dynamics (CFD) mesh grids. This software was evaluated in this study for potential use and inclusion into ModelCenter, but due to time constraints and the requirement to learn a new language in order to apply the software, it was not incorporated. Parametrical in nature, strengths of the program include the ability to make and see instant changes in the design and compute any number of outputs. GGG produces geometry that is a continuous function of the input parameters, a property not typically available in commercial systems, enabling geometry to morph continuously between different shapes, and preventing downstream problems with geometry discontinuities.

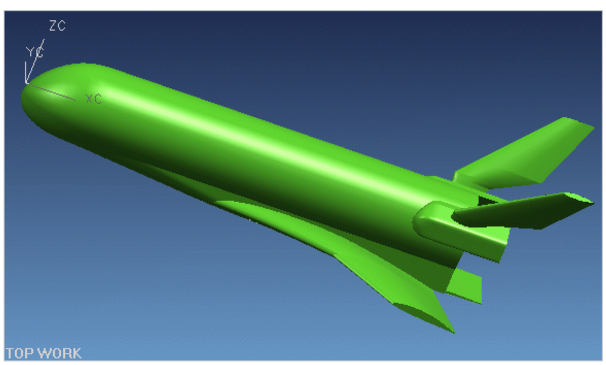


Figure 23 Example GGG Display

There is a significant startup learning cost to the program as extensive coding experience in Python is required to create the models. Once the models are formed they

can be wrapped into ModelCenter and used to interact with other model variables. The current GGG process requires manual construction and assembly of the geometry using a set of geometry generators, highly specialized tools to create loft surfaces for aircraft components given a set of constraints such as locations, tangents, section curves and parameters. The types of geometric generators are: Airfoils (wings, vertical and horizontal stabilizers), Nacelles (tubes, engine cowling, fuselages), and Fairings (fairings, cowlings, fuselages, pods).

The geometric components, and their relative positions are parameterized and normalized to lie between 0 and 1, so that any combination of inputs within this parametric hypercube will produce a valid aircraft configuration. Using a Design of Experiments (DOE) the designer can explore the design space, producing a whole family of designs, which can then be evaluated for performance. The data can then be used to plot surrogate mathematical models (Response Surfaces), which can be used to find design optima.

Initial Historical Sizing

Initial weight sizing was conducted according to chapter 3 of Raymer's conceptual design text "Aircraft Design: A Conceptual Approach", (ref. 2) which contains many equations and graphs based on historical trends and trend analysis. For many aircraft types, history is a good benchmark for replacement designs. Using these equations one can rapidly conduct a rapid "back of the napkin" design analysis for a number of different types of aircraft. This simplest analysis is incapable of handling payload, ordnance or

fuel tank drops, and while somewhat crude, it provides a rapid ballpark figure (+/- 20%) of the actual take-off gross weight (TOGW).

Weight Buildup

Design gross takeoff weight is comprised of crew weight, payload weight, fuel weight and empty weight, which includes the structure, propulsion and fixed equipment as shown in the equations below.

$$W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty} \tag{6}$$

$$W_{empty} = W_{structure} + W_{propulsion} + W_{fixed} \tag{7}$$

For the simplest analysis to find W_0 , assuming both payload and crew weights are given as requirements, one needs a empty weight fraction (W_{empty}/W_0) and a fuel fraction (W_{fuel}/W_0) as both the fuel and the empty weight are dependent on W_0.

Empty Weight Fraction

An empty weight fraction is calculated based on the type aircraft and the estimated TOGW (W_0) in Table 3.1 in (ref 2), displayed in chart form as figure 24 for a several different aircraft types.

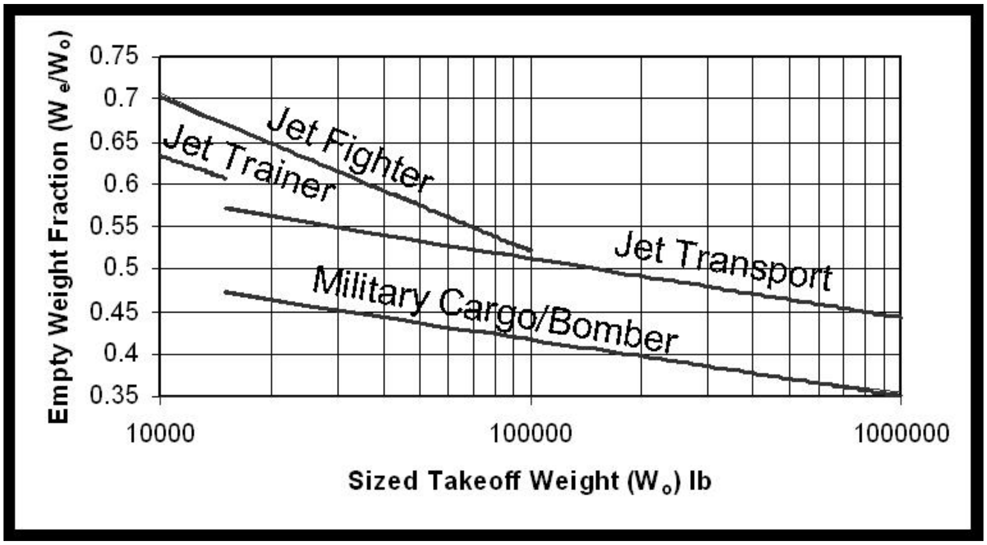


Figure 24 Weight Fraction Empty Trends (ref. 2)

These logarithmic curve fits are from Raymer's own calculations using publicly available data from Jane's and other sources.

Fuel Fraction

For any given mission, the analysis is broken up into various portions or "legs." The ASW mission profile given by Raymer consists of seven legs as shown below.

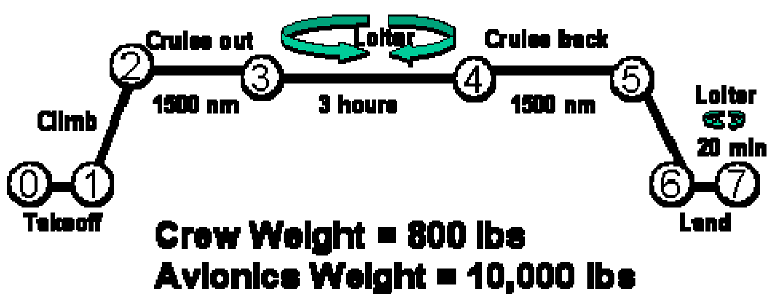


Figure 25 ASW Mission

Some mission segment weight fractions are estimated using historical trends as given in table 3.2 in reference 2.

Table 7 Approximate Mission Weight Fractions (ref. 2)

Mission Segment	(W_i/W_{i-1})
Warmup and takeoff	0.970
Climb	0.985
Landing	0.995

Cruise segments and loiter segments weight fractions are calculated using the Breguet Range Equation (ref. 2, ch17) and the Endurance Equation. (ref. 2, ch17)

$$W_i / W_{i-1} = e^{\left(-RC / V(L/D) \right)} \tag{8}$$

where R = range (ft), C = specific fuel consumption (SFC), V = velocity (ft/s) and L/D is lift-to-drag ratio.

$$W_i / W_{i-1} = e^{\left(EC / (L/D) \right)} \tag{9}$$

where E = endurance or loiter time (in seconds or hours). Units need to be consistent. If SFC is given in lb_m/lb_f-hr, then endurance can be given in hours.

By multiplying all the weight fractions for each segment, one can determine the ratio of weight at mission end to starting weight (W_{end}/W_0), where ending weight is the weight after landing, taxiing, and shutting down. The empty weight fraction (W_{empty}/W_0), then can be calculated as ($1-W_{end}/W_0$), assuming all fuel available is usable and end weight is empty weight.

However, for safety considerations and physical limitations of the fuel system, not all the fuel available can be used. Raymer estimates 5% for reserve, and 1% for trapped fuel, so the empty weight fraction becomes ($1.06 - W_{end}/W_0$).

Specific Fuel Consumption (SFC)

Next, typical values for cruise and loiter SFCs are selected from a table of engine types (ref. 2, table 3.3), shown below.

Table 8 Specific Fuel Consumption (ref. 2)

Typical jet SFCs: 1/hr	Cruise	Loiter
Pure turbojet	0.9	0.8
Low-bypass turbofan	0.8	0.7
High-bypass turbofan	0.5	0.4

Lift-to-drag ratio (L/D) Estimation

L/D is a measure of the total aerodynamic characteristics of the design. In level unaccelerated flight, to maintain equilibrium, lift (*L*) must be equal to aircraft weight (*W*) and thrust (*T*)must be equal to drag (*D*). In the subsonic flight regime lift is most directly affected by the wing aspect ratio (*AR*) and the wing planform area (S_{ref}). Induced drag is a function primarily of *AR* and zero-lift drag, which is mostly due to skin-friction which is proportional to the wetted area of the aircraft (S_{wet}).

Aspect Ratio (*AR*) is defined as the ratio of the span squared to the planform reference area (S_{ref}) of the wing. Effective Aspect Ratio (AR_e) is equal to the span squared divided by some total S_{ref}, usually of the wing and wing extension or "yehudi."

$$Aspect\ Ratio\ (AR) = \frac{b^2}{S_{ref}} \quad Effective\ Aspect\ Ratio\ (AR)_{eff} = \frac{b^2}{(S_{ref})_{total}} \qquad (10)$$

Wetted aspect ratio (*WAR*) is the *AR* divided by the ratio of the S_{wet}/S_{ref} or span squared divided by wetted area (S_{wet}).

$$Wetted\ Aspect\ Ratio\ (WAR) = \frac{b^2}{S_{wet}} = \frac{AR}{\left(S_{wet}/S_{ref}\right)} \tag{11}$$

From a conceptual sketch this value can be determined which can then be used to develop a preliminary L/D value with the aid of historical trends for various aircraft as given in table 3.6 of ref. 2.

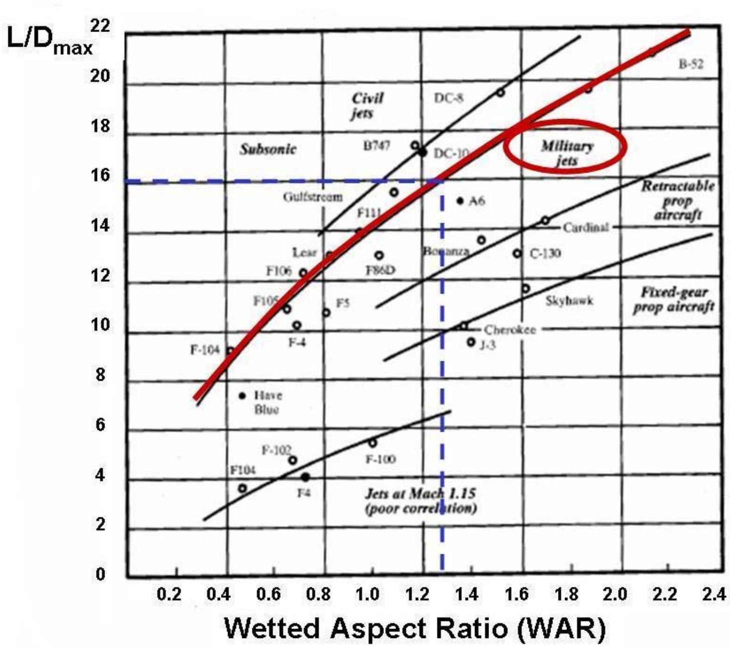


Figure 26 Maximum Lift-to-Drag Ratio Trends (ref. 2)

In order to use this table without manually looking up values, Table 3.6 “military jets” data was entered into an Excel spreadsheet and an exponential curve fit was applied to the points and extrapolated to beyond the L/D and WAR values shown in the table.

Then a simple Visual Basic Script (VBScript) was coded in ModelCenter to input Wetted Aspect Ratio (WAR) and return L/D_{max} based on the curve fit in equation (11).

$$L/D_{max} = 14.081(WAR)^{0.4898} \tag{12}$$

In Raymer's approach S_{ref} is determined from a conceptual sketch and S_{wet} is guessed by aid of a visual historical chart of current designs. For this study, S_{ref} and S_{wet} were determined from calculations of aircraft geometry in ModelCenter, aided by some MATLAB calculation routines.

First Order Design Method Overview

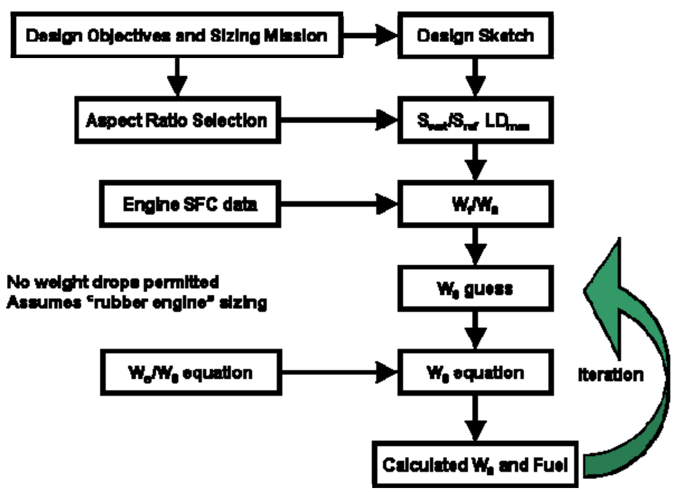


Figure 27 First -Order Design Method (ref. 2)

For new build aircraft, an Aspect Ratio (AR) is selected and a design sketch is generated, providing a preliminary guess at the lift-to-drag (L/D_{max}) ratio needed to meet mission and design objectives based on the S_{wet}/S_{ref} ratio, or WAR. "Rubber Engine" or scaled engine sizing is used to provide approximate SFC for a class of engines in cruise or loiter conditions, and then W_f/W_o can be generated from historical trends. Starting

from an initial W_o guess and using Breguet endurance and range equations W_o and W_{fuel} can be calculated. This new W_o is then used as the W_o guess and the process is iterated until the calculated W_o converges at the guess W_o. This process (fig. 26) can be sped by inputting data into an Excel spreadsheet (App. E).

Of note, Raymer's *ASW sizing calculations* (Box 3.1 ref. 2) are in error, the W_7/W_0 value should be 0.644 when cruise leg 5 weight fraction is input correctly. If correction is carried through, the final converged weight becomes 56,732 lbs vice printed value of 59,309 lbs.

Refined Sizing

Refined weights were obtained by using an improved, semi-historical equation (ref.2, Table 6.1) for the calculation of the empty weight fraction (W_{empty}/W_0).

$$W_e/W_o = \left[a + b W_o^{c1} A^{c2} \left(T/W_o\right)^{c3} \left(W_o/S\right)^{c4} \left(M_{\max}\right)^{c5} \right] K_{vs} \quad (13)$$

where a, b, c1, c2, c3, c4, c5 are constants for each type of aircraft. K_{vs} is 1.0 for a fixed sweep wing and 1.04 for a variable sweep wing, A is Aspect Ratio, W_o is TOGW, (T/W_o) is takeoff thrust-to-weight ratio, (W_o/S) is takeoff wing-loading, and M_{max} is the maximum design Mach number. In order to determine the wing loading (W/S) and thrust-to-weight (T/W) the methods chapter 5, reference 2 were employed.

All of the models built were developed as Bomber aircraft, as that most closely resembles the mission, role and sizing. For the "Military Cargo/Bomber" aircraft, a quick analysis was conducted on the empty weight equation to determine the sensitivity of the

empty weight fraction to variable input (fig. 28). Variables selected were representative of the design space for Bomber-type aircraft.

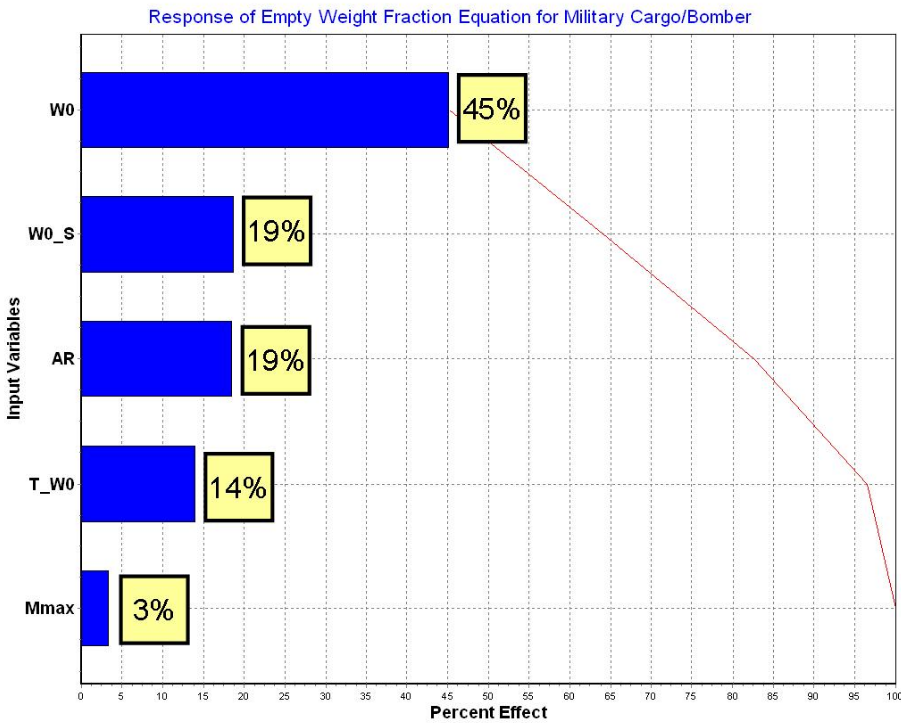


Figure 28 Sensitivity Analysis of Empty Weight Fraction Equation

Results show that the equation is primarily affected by the TOGW (W_0) term, minimally by M_{max}, and nearly equally by the other three terms. Classic *T/W* versus *W/S* plots could also be produced at this stage in order to constrain the design space. As no specific performance values were given for turn, climb rate, takeoff, or landing this was not required for the three models, but a sample response surface for the Raymer ASW model is given in figure 29.

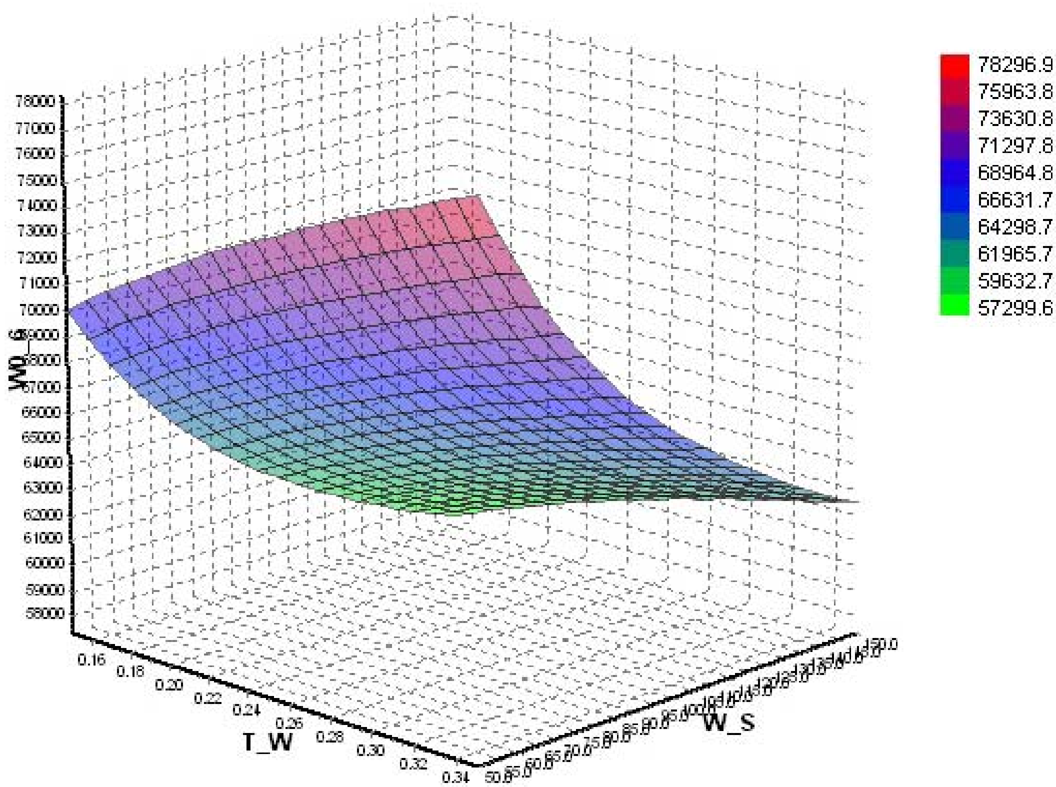


Figure 29 Response of Refined Weight to T/W and W/S Inputs for Model (2) Raymer ASW Aircraft

Semi-empirical Sizing

ACSYNT

Sizing was then performed with ACSYNT, by "wrapping" an ACSYNT input file (filename.IN) and its produced output file (filename.OUT) with an associated filewrapper. The filewrapper saved to the ModelCenter Analysis Server can then be added to the model and the parameters linked to model input values and ACSYNT outputs. Appendix D contains input and output files for each model.

Many of the model problems and limitations stem from using this legacy code. First of all are the geometric representation limitations. ACSYNT only allows one $WING namelist, one $HTAIL namelist, one $VTAIL namelist and one $FUS namelist.

For the joined-wing configuration this created a problem, due to the joined wing having two wings: a fore and aft wing. It was decided to model the aft wing as a horizontal tail and the boom segment as a vertical tail. Because the $HTAIL namelist does not include a provision for supplying the anhedral or dihedral, the projection of the aft wing onto the horizontal plane was used, and the reference area, and aspect ratio for the vertical tail was modified according to the aft wing's projection onto the vertical plane. The wing was modeled by a $WING namelist that extended to the centerline of the vehicle, and had a rear extension that reduced the effective aspect ratio, by adding in additional S_{ref}.

Secondly are trajectory errors. The trajectory module is highly error prone, even for seemingly good profiles. This has been previously identified, but not solved.

Lastly are interface errors with ModelCenter. When running a wrapped ACSYNT file, and the component has to be halted for any reason, ModelCenter would orphan the process on the Analysis Server, with no direct indication to the user, other than the next run would not complete. The spinning hourglass of death, and locked files on the Analysis Server were indications that something was still executing ACSYNT. In order to resolve the problem, the applications had to be terminated on the Analysis Server by computer support technicians.

Other errors that are common with ACSYNT incorporation into ModelCenter are the formatting of numbers, which is done according to FORTRAN formatting standards, where fformat = F5.3, means "fixed number formatting with five total characters and three characters after the decimal." In this schema, the number 4.333 would be fine, but the number -0.500 would produce errors, as it has six total characters, four numbers, the period and the minus sign. ACSYNT input files contain both integer, real and Boolean

values, and it is important to distinguish among them. It is best to list all the reals together, then integers and then the Boolean values.

Raymer Approximate and Group Weights Sizing Methods

The formulas of reference 2, chapter 15 for *Approximate Empty Weight Buildup* (Table 15.2) and the statistical weights method (15.3) were used to estimate the component weight breakdown of the vehicle. Comparison of weights is shown in chapter IV. Of note, the group weights sizing method is dependent on many additional parameters, some of which are default values, in lieu of actual engineering design information.

Finite Element Model Structural Weight

For the joined-wing model, the structural weight was also determined by utilizing the FEM for the 410E model through NASTRAN queries. Due to the historical nature of the empirical estimating codes (initial, refined, approximate weights, and group weights) the joined-wing structural weight must be determined in an alternate manner. Although not optimized, the model was evaluated for change in structural weight due to geometric changes, via a MATLAB code, which is discussed in detail in the next chapter.

IV. *Results and Discussion*

Model Construction

Before any model can be constructed, valid data sets need to be integrated from the various sources of parameter information. Key model parameters and sources are shown in table 9, details in appendix A.

Table 9 Key Model Parameters

Parameter	S-3 Viking	Raymer Canarded ASW Aircraft	Joined-Wing SensorCraft (410E)
Wingspan (b)	68 ft 8 in	68 ft	150 ft
Length (LOA)	53 ft 4 in	51 ft	98 ft
S_{ref}	598 ft^2	510.4 ft^2 + 156.8 ft^2 **	1980 ft^2 + 775.5 ft^2 ***
Wing airfoil (root)	NACA 0016-53	NACA 0016-53	Custom airfoil
Max internal fuel	13444 lbs (1,933 US gal)	Limited by volume	Limited by volume
Max fuel	17617 lbs (2533 US gal)	Limited by volume	Limited by volume
Empty Weight	26581 lbs	Unknown (~30000 lb)	50674 lb
Max GTOW	52539 lbs	Unknown (~60000 lb)	~115000 lb
Propulsion	2×GE TF-34-GE-2 turbofans	2× turbofans (improved)	2×turbofans
Engine Thrust (SL)	9300 lbf	~11000 lbf	30000 lbf
Engine Weight	1421 lbs each	~1421 lbs each	11977 total propulsion
Engine Length	8.33 ft	~8.33 ft	-
Engine Diameter	4.167 ft	~4.167 ft	-
Wing loading W/S):	68.5 lb/ft^2	~60-100 lb/ft^2	-
Thrust/weight T/W):	0.353	~0.25-0.45	-
Max Diameter	7.5 ft	8 ft	8.8 ft (fuselage height)
Principal Information Sources	S-3 NATOPS (ref. 4) Wikipedia	Raymer text (ref. 2)	Boeing FEM, CAD, Literature (ref. 21)
Calculations		*Derived from Geometric Parameters*	
S_{wet}	2811.0 ft^2	2721.6 ft^2	7782.9 ft^2
AR_{eff}	7.750	6.923	8.166
WAR	1.649	1.2984	2.89
S_{wet}/S_{ref}	4.7	5.33	2.82
L/D_{max}	16.0 used (calc. 18.0)*	16.0	23.7
*	For comparison L/D was manually held at 16 for initial/refined sizing		
**	S_{ref} shown is for wing and canard areas		
***	S_{ref} shown is for forward wing including yehudi		

S-3 Validation Model

Objective

The objective behind the validation model was to determine to what level of accuracy ACYSNT could estimate fuel weights and TOGW for a conventional design with known structural weights, before attempting to determine the TOGW of a semi-conventional design, and all but the structural weight of a Joined Wing model.

S-3 Model

The Lockheed S-3 "Viking" is a high-wing twin-turbofan powered, carrier-based antisubmarine warfare (ASW) aircraft, with a crew of four. Aircraft layout is shown as in figure 30.

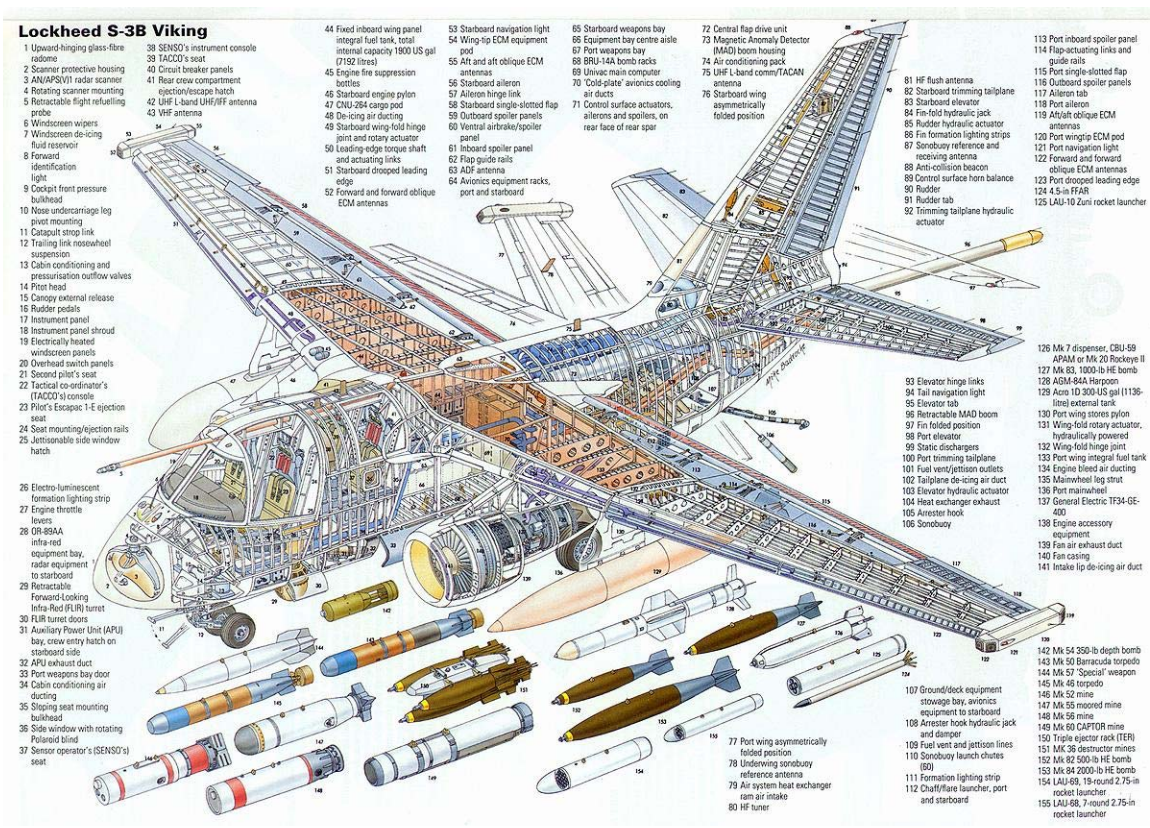


Figure 30 Lockheed S-3 Viking

Geometry

The model was first constructed in ModelCenter component by component, using custom-defined ruled surfaces for the nose and a rounded-rectangular super-elliptical fuselage, described in chapter 3. The geometry data was taken from publicly available technical data and the S-3 NATOPS manual. (ref. 4)

Wings and tail were created via the standard aircraft geometry components (wing) available on the Analysis Server and MATLAB code was used to determine the wetted area (S_{wet}) and available volume of the shapes. ACSYNT's S_{wet} calculations tended to overestimate by about 3-4%, so wetted area multipliers (SWFACT) were applied as required.

Initial and refined sizing were then conducted and calculations were added to provide needed ACSYNT data. This data was then used to build an input file (S3.IN – App A) which contained the geometrical information, mission profile, aerodynamic characteristics, and propulsion data and any fixed weight information.

Trajectory

The two missions compared were (1) an actual high-low-high ASW mission (ref. 4) as depicted in figure 31, and (2) Raymer's theoretical ASW mission (ref. 2) as shown in figure 32. The two missions are compared in table 10.

Table 10 ASW Mission Comparison

Mission Segment	Mission (1) Actual S-3 HI-LO-HI ASW	Mission (2) Theoretical HI-HI-HI ASW
Warmup and Taxi	**(0)** 5 minutes at idle power	**(0)** 5 minutes at idle power
Takeoff	**(1)** 1 minute at Mil power	**(1)** 1 minute at Mil power
Accelerate	**(2)** Accelerate to 0.33M	*Not modeled*
Initial Climb	**(3)** Climb to 15K ft	**(2)** Climb to 30K ft
Accelerate	**(4)** Accelerate to 0.59M	*Not modeled*
Ingress Cruise	**(5)** 0.59M at 15K ft (635 nm)	**(3)** 0.6M at 30K ft (1500 nm)
Pre-Loiter Climb/Descent	*Not modeled*	*Not modeled*
Loiter	**(6)** 0.34M at 100 ft (1 hr)	**(4)** 0.6M at 30K ft(3 hrs)
Expendables Drop	*Not modeled (1060 lbs)*	*Not modeled*
Post-Loiter Climb/Descent	**(7)** Climb to 10K ft	
Egress Cruise	**(8)** 0.59M at 10K ft (635 nm)	**(5)** 0.85M at 30K ft (1500 nm)
Final Descent	*Descent credit of 80 nm*	*Descent credit of 80 nm*
Reserve Loiter	**(9)** 20 minutes at SL	**(6)** 20 minutes at SL

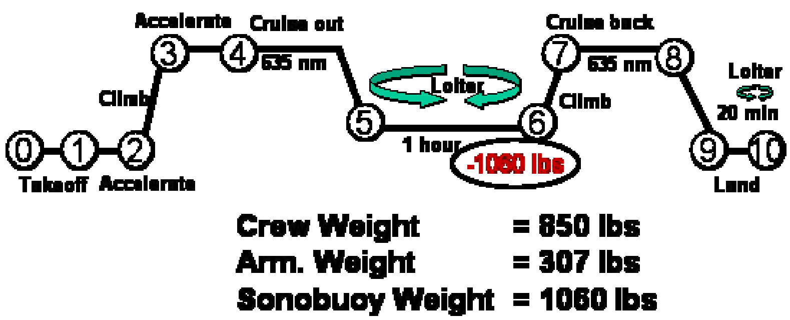


Figure 31 Mission (1) HI-LO-HI ASW Mission (Actual S-3)

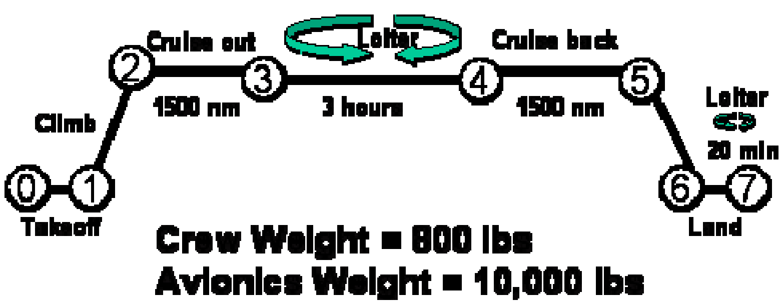


Figure 32 Mission (2) HI-HI-HI ASW Mission (Raymer)

Aerodynamics

The S-3 uses a symmetrical 0016-53 airfoil for the main wing and a NACA 0012 airfoil for the vertical tail, and a NACA 2410 for the horizontal tail. Flap settings for takeoff and landing maneuvers are given in S-3 NATOPS manual (ref. 4).

C_{L0} values were determined from the given airfoils, applied to the wing. For both the S-3 and ASW models the value was zero based on a symmetric airfoil mounted at zero degrees incidence.

ACSYNT defaults to automatically perform a drag analysis (ICDO=0) based on component geometry drag build up, and provides an estimated drag for each flight condition analyzed. These output numbers were checked manually using an Excel spreadsheet with component drag buildup equations of reference 2, chapter 12 at the cruise flight condition and local Reynolds number for each component. For the S-3 model ACSYNT estimated C_{D0} to be 0.01270 for the outbound cruise portion, the manual calculation determined a C_{D0} of 0.01355.

Propulsion

The TF-34-GE-2 turbofan is one of the six standard engines contained within ACSYNT, selection 6. It is a high-bypass turbofan engine with a bypass ratio of 6.24, a seal-level static thrust of 9300 lbf, and an engine weight of 1425 lbs.

Weights

Components of known weight were fixed in ACYSNT by way of the Fixed Weights namelist ($FIXW). Fixed weights were as follows:

Table 11 S-3 Fixed Weights Breakdown

Component	Fixed Weight Mission (1)	Fixed Weight Mission (2)
Wing	4890 lbs	4890 lbs
Fuselage	5067 lbs	5067 lbs
Horizontal Tail	769 lbs	769 lbs
Vertical Tail	585 lbs	585 lbs
Nacelles	806 lbs	806 lbs
Landing Gear	1670 lbs	1670 lbs
Total Structure	***13787 lbs***	***13787 lbs***
Engines	2951 lbs	2951 lbs
Fuel System	346 lbs	346 lbs
Propulsion	***3297 lbs***	***3297 lbs***
Hyd & Pneumatic	389 lbs	389 lbs
Electrical	1098 lbs	1098 lbs
Avionics	4353 lbs	4353 lbs
Instrumentation	174 lbs	174 lbs
De-ice & Air Cond.	951 lbs	951 lbs
Aux Power System	1144 lbs	1144 lbs
Flight Controls	1604 lbs	1604 lbs
Fixed Equipment	***10009 lbs***	***10009 lbs***
Cargo*	932 lbs	1039 lbs
Flight Crew*	850 lbs	850 lbs

*Cargo weights differ due to need to sum total payload (cargo, crew weight, all other operating items) to equivalent payload weight of ~ 2271 lbs, the specified weight in ref. 4.

After the input file was completed, it was run manually in ACSYNT to see if it produced errors. After all the errors were finally corrected, and a valid output was obtained, a filewrapper was written to map the input and output files to the ModelCenter program. The filewrapper when stored on the Analysis Server with the required template file (a “golden copy” of the original input file), could then be inserted into ModelCenter. After the “wrapped” component was inserted into the model, the parameters were manually linked from the current model to the wrapped component.

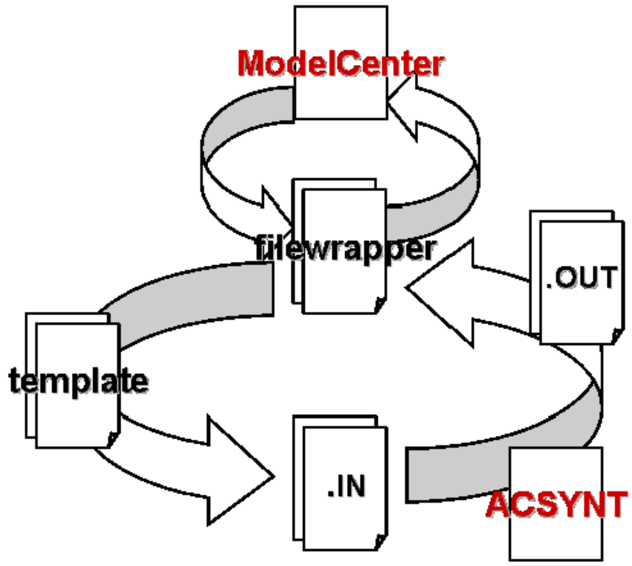


Figure 33 ACSYNT Integration with ModelCenter

Results

For the S-3 Model, the fuel was estimated to within 12% of the actual fuel required for the S-3 NATOPS mission. The fuel numbers were high due the use of a TRANSPORT type aircraft, when in fact the BOMBER type would have been more appropriate. This was an unfortunate circumstance of licensing and support issues surrounding the use of ACSYNT for aircraft types other than TRANSPORT. The TRANSPORT type aircraft are restricted from the carriage of armaments (WARM) and ammunition (WAMMUN) and lack the ability to expend weight (armaments or ammunition) at some point in the mission. As a result, the additional weight had to be carried throughout the mission, which resulted in a correspondingly higher fuel weight.

The weights are also grouped differently in the ACSYNT output as shown below.

Table 12 Comparison of TRANSPORT and BOMBER Weight Categories

BOMBER	***TRANSPORT***
Operating Items	**Operating Items**
Flight Crew	Flight Crew
Armaments	Crew Baggage and Provisions
Ammunition	Flight Attendants
Missiles	Unusable Fuel and Oil
Bombs	Passenger Service
External Tanks	Cargo Containers
Adv. Weapons 1	**Payload**
Adv. Weapons 2	Passengers
	Baggage
	Cargo

In order to apply the 2217 lb payload of 1060 lbs of sonobuoys (WAMMUN), 850 lbs crew weight, and 307 lbs armaments (WARM), the cargo weight had to be varied in order to provide an equivalent weight as the crew weight was already accounted for, and other TRANPORT related weights (Crew Baggage and Provisions, Passenger Service and Cargo Containers) accounting for 293 to 383 lbs in all, were not able to be set to zero.

The TOGW values were within 4% of the truth baseline. It is expected, that with the use of the BOMBER type aircraft, the accuracy could be improved to within 1- 2%.

Table 13 S-3 NATOPS and ACSYNT Weight Comparison for Mission (1)

Component Weight	NATOPS values (ref. 4)	ACSYNT Calculations	Percent Difference
Structure	13786	13787	-
Propulsion	3296	3297	-
Fixed	10008	10009	-
Empty	27090	27093	-
Operational	2271	2283	0.5 %
Fuel	13244	14930	12.7%
GTOW	42605	44306	4.0%

Impact

ACSYNT should be able to provide accurate estimations of fuel required within 10% of the baseline value, but due to using a TRANSPORT-type aircraft, no mission weight drops can be made. This effect will not be seen for the ASW model and the joined-wing model as there are no payload or stores drops in the mission profile.

Raymer's Canarded ASW Aircraft

In his text (ref. 2), Raymer discusses a hypothetical ASW mission (fig. 31) and a family of conceptual designs (fig. 33) that could be used to meet the mission.

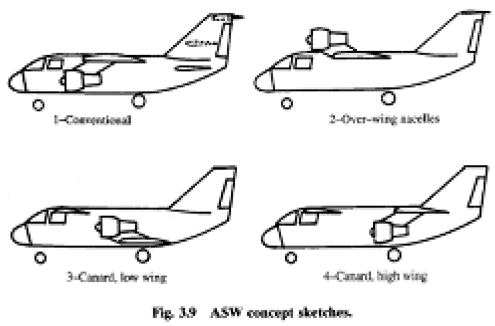


Figure 34 ASW Concept Sketches

Mission and aircraft specifics are as shown below.

Table 14 ASW Aircraft/Mission Requirements

3 hr loiter @30K ft	10,000 lb = payload	Wing AR = 10	High Bypass TF
1500 nm range	800 lb = crew wt	WAR = 1.27	SFC_{loiter} = 0.4
0.6 M cruise @30K ft	L/D_{max} = 16	AR effective = 7	SFC_{cruise} = 0.5
	L/D_{cruise} = 13.9	S_{wet}/S_{ref} = 5.5	

Overview

This model was originally to serve as the principal validation model, but due to the fact that it is only a conceptual "paper airplane," and not a production design, very little information existed in order to build the model, and the only near comparison was

its inspiration, the S-3 Viking. The Viking, however, can not perform the proposed ASW mission as it carries a maximum of 17731 lbs of fuel, (13351 lbs internally), and ACSYNT results show that it would need 22630 lbs of fuel to fly the required profile of Mission (2). In order to complete the mission, the aircraft would have to be scaled accordingly larger. The ASW aircraft therefore is expected to be heavier in weight than the S-3. The Anti-Submarine Warfare (ASW) Model data came from a variety of sources. The chief sources were Lockheed's S-3 Viking and Raymer's ASW aircraft (ref. 2), a canarded conceptual design loosely based on the Viking. (fig. 35) Raymer's sketch is shown overlaying the ModelCenter geometry.

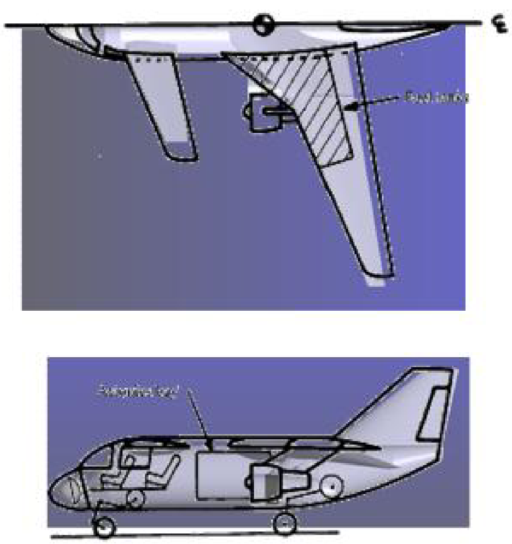


Figure 35 Comparison of Raymer's ASW Sketch and ModelCenter Aircraft

Geometry

The visible geometry differences, a thinner, longer wing and a shorter canard are due to attempts at simultaneously satisfying the AR_{eff} requirement of ~7, and a S_{wet} to S_{ref} ratio of 5.5, to reach a Wetted Aspect Ratio (WAR) of 1.27, set by Raymer to attain an

L/D_{max} of 16. When the L/D table is coded ($L/D_{max} = 14.081(WAR)^{0.4898}$) an AR of 1.2984 equates with an L/D of 16, and was maintained to drive the model an L/D of 16.0.

Since no real flying model exists, several assumptions were made in the model's construction. The fuselage maximum diameter was set at 8.0 ft, and the length at 51 ft, and the design tried to mimic the plan and profile shapes of the sketch while attempting to meet a combined AR of 7, with a wing AR of 10. Actual combined or effective AR for the model was 6.923, and S_{wet}/S_{ref} was 5.33.

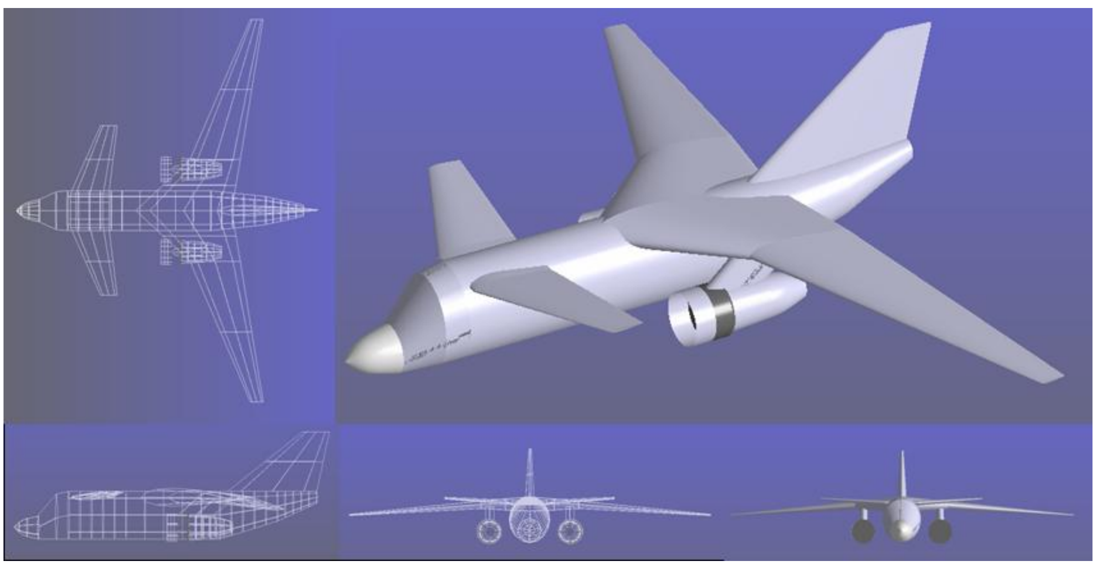


Figure 36 ASW Aircraft Modeled in ModelCenter

Adaptability is a key component of the design of the ASW model; changes made in the geometry echo into the analysis codes and allow rapid analysis, visualization and recording of different designs. However, the ACSYNT input files must still be modified for radical changes in design, for example the addition of a horizontal tail would require the addition of the $HTAIL namelist to the ACSYNT input file, a modification of the

filewrapper and a relinking of components within ModelCenter, required any time the filewrapper is changed.

Despite these difficulties the ability to tweak a given design for certain performance and see changes in real time is exceptional. As a sample of the model's flexibility figure37 is presented. All but the S-3 design share exactly the same wing planform, and engine size. None of these designs are presented as optimal or even flight worthy, but serve as an example of the flexibility of the Visual Basic Script (VBS) component location routine.

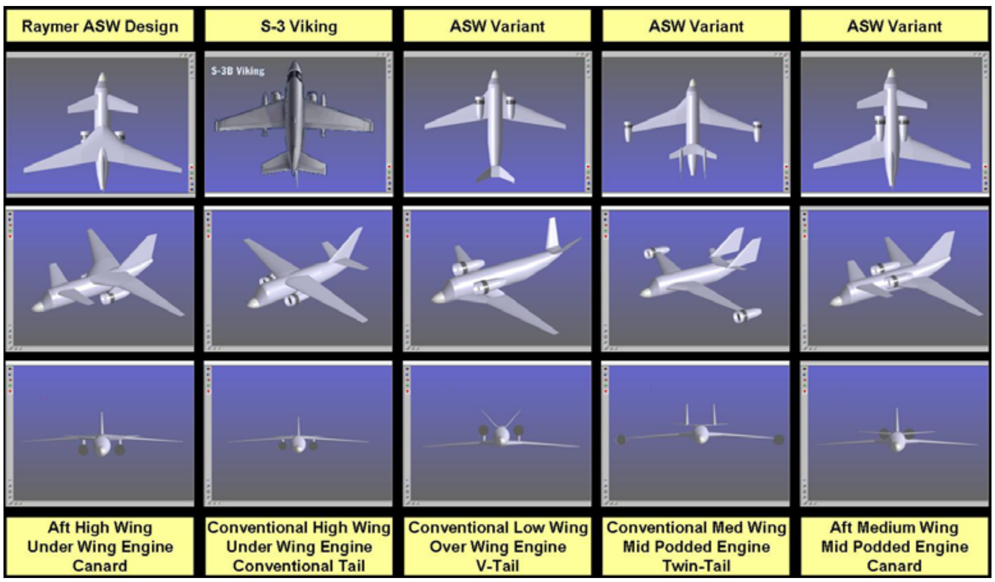


Figure 37 Model Center ASW Variants

Using enumerated values and integrated calculations embedded in Visual Basic Scripts (VBS) the user can select from various drop-down menus in the Data Monitors within ModelCenter the following options:

Wing/Canard z location – choice of high, medium, or low mounted wing.

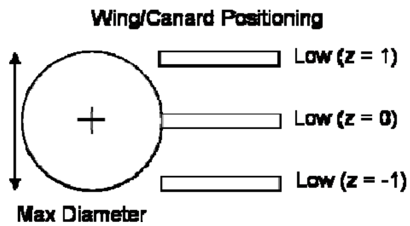


Figure 38 Wing Canard Positioning as Fraction of Fuselage Radius

Wing/Canard/VTail x location – as percentage of overall fuselage length (LOA).

Horizontal tail type – select from conventional, twin-tail, T-tail, V-tail, U-Tail.

Horizontal tail x location – positions tail as a percent of vertical tail chord

Engine type (z location) – select from overwing, underwing, or podded.

Engine y location – select from wing, fuselage, or wingtip.

Engine x location – select from engine position forward, middle or aft.

The fuselage shape is controlled by the length overall (LOA), six sectional percentages (Radome, Nose, Forward, Mid1, Mid2, and Aft), cross-sectional characteristics (ellipse, rounded rectangle, square, etc) and vertical or horizontal offsets based on the MATLAB super-ellipse code.

Propulsion

The same basic engine deck was initially used for this aircraft, though it was later determined an increase in thrust would be required to sustain cruise at 30K ft, and a Engine Scaling Factor (ESF) was incorporated to size the engine accordingly.

Results

Table 15 compares the ACSYNT runs for the canarded ASW aircraft and the S-3. The ASW aircraft is predictably larger, and uses significantly more fuel than the S-3. This is due in part to a larger C_{D0} by 23 counts and lower wing efficiency. It is possible

that a canarded design could achieve better performance, but redesign of the aircraft was not part of this work. Also of note are the lower structural weight values, presumably because the TRANPORT type was used, versus the BOMBER type. One of the drawbacks of using a compiled C code version of ACSYNT is the inability to drill down into the code. The fixed weights and propulsion weight meet expectations.

Table 15 Canarded ASW Aircraft and S-3 Weight Comparison for Mission (2)

Component Weight	S-3 ACSYNT Calculations	ASW ACSYNT Calculations	Percent Difference
Structure	13786	9637	30.10%
Propulsion	3296	3695	12.11%
Fixed	10009	9592	4.17%
Empty	27093	22924	15.39%
Operational	2271	1067	53.02%
Fuel	22630	35287	55.93%
TOGW	51989	59278	14.02%

The results of the different weight estimation methods are presented below for the canarded ASW aircraft performing the Mission (2) HI-HI-HI ASW. As discussed previously the ACSYNT Model of the ASW aircraft suffers from low wing efficiency, on the order of 0.25, and therefore has much higher fuel fractions and lower empty weight fractions.

Table 16 Comparison of Weight Estimation Methods for the Canarded ASW Aircraft

			Sizing Method		
Component Weight	Initial (ref.2)	Refined (ref.2)	ACSYNT	Group Weights (ref. 2)	Approx. Weights (ref. 2)
Structure	-	-	9637	12369	13135
Propulsion	-	-	3695	4420	-
Fixed	-	-	9592	15776	19644
Empty	24739	32090	22924	33504	26474
Operational	800	800	1067	1000	800
Fuel	21411	25343	35287	25343	25343
TOGW	56732	66742	59278	58907	61069
W_e/W_0	0.44	0.48	0.39	0.57	0.42
W_f/W_0	0.38	0.38	0.60	0.43	0.40

Impact

The canarded ASW aircraft is not easily modeled in ACSYNT, due to the system limitation of not permitting trimming canards. As a result, the associated trim drag is higher than expected and the aircraft has low wing efficiency, producing a heavier than expected aircraft. The joined-wing ACSYNTmodel will behave more like a conventional aircraft in trim and should not suffer the same drag penalties.

Boeing SensorCraft Joined Wing (410E)

Introduction

The ModelCenter integration environment was again utilized to construct and store all the pertinent variables for Boeing's joined-wing SensorCraft. First, a model was built to match the 410E CAD data, based on manual 3-view measurement pickoffs. After the AEI report was issued, the model was altered to reflect the more accurate measurements. Data from the SensorCraft 410D model, (similar planform to 410E, except pointed wing tips, and wider outboard chord), shown in inches, is shown in fig 39.

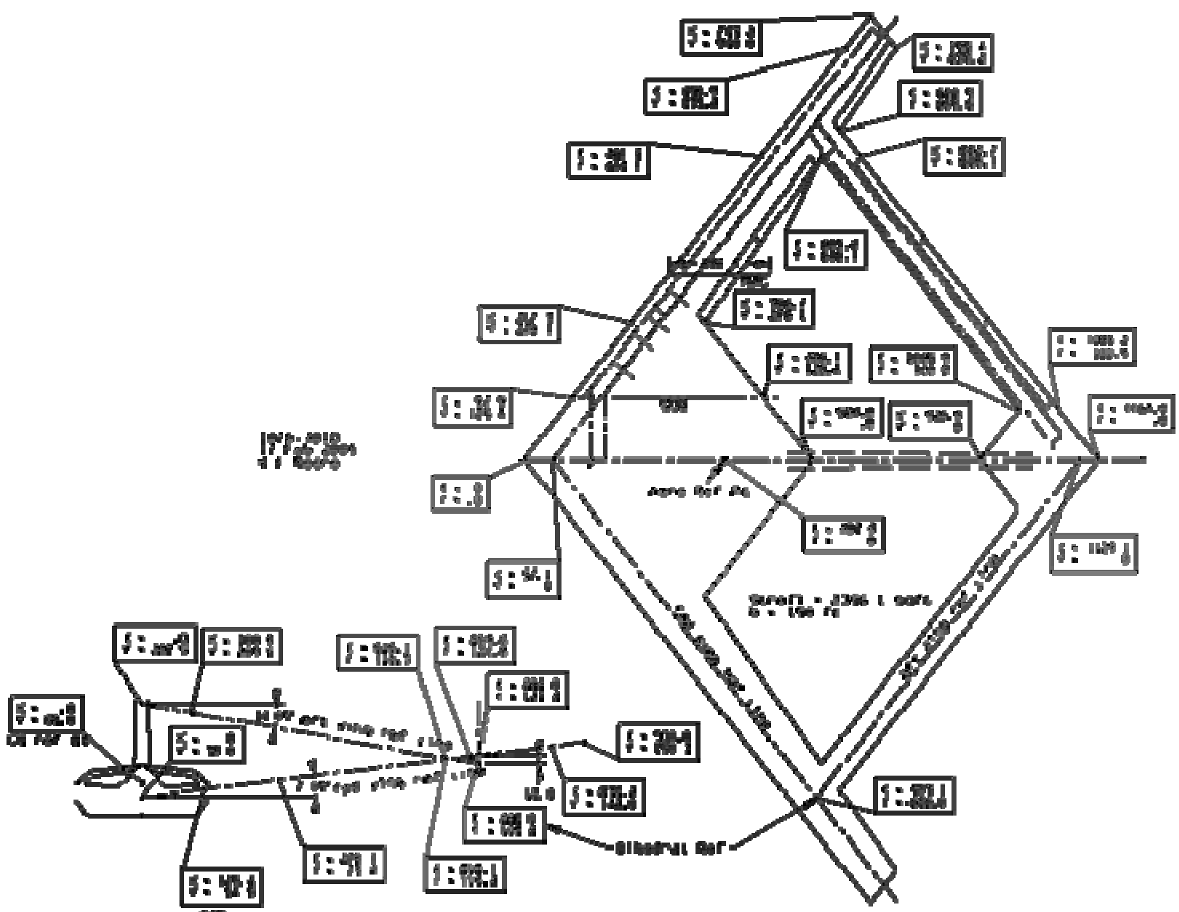


Figure 39 Boeing SensorCraft 410D Point-of-Departure Layout (ref. 21)

Surrogate ACSYNT input Model

A surrogate model was also constructed to facilitate input of parameters into ACSYNT, as the Joined Wing design cannot be exactly duplicated in ACSYNT and was simplified in order to model in ACSYNT. It was represented as a fuselage, a wing, horizontal tail (aft wing) and a vertical tail (boom).

The forward wing was represented as a $WING object in ACSYNT, extending from the aircraft centerline to the wingtip, and using an effective aspect ratio, wing span squared divided by the sum of the wing and the yehudi reference areas, and a total reference area, wing plus yehudi, as inputs. (fig. 40) The yehudi or aft strake is a Boeing term used to describe the inboard trailing edge extension.

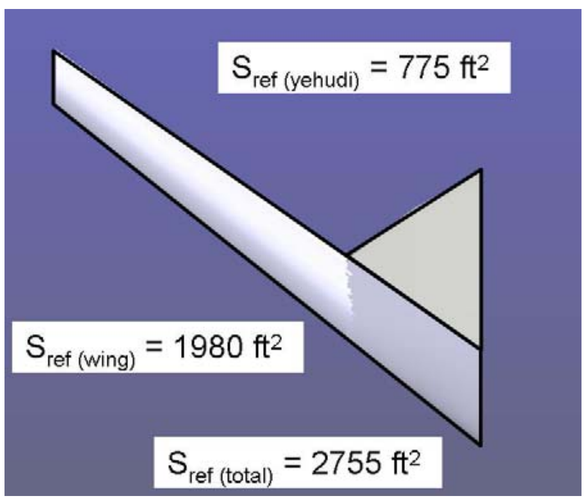


Figure 40 Reference Areas for Wing

A similar arrangement was used for the aft wing, which was modeled as an $HTAIL object in ACSYNT, as two $WING objects are not permitted. $HTAIL objects in ACSYNT do not have a modifiable dihedral parameter, as the surrogate model (fig. 41) shows.

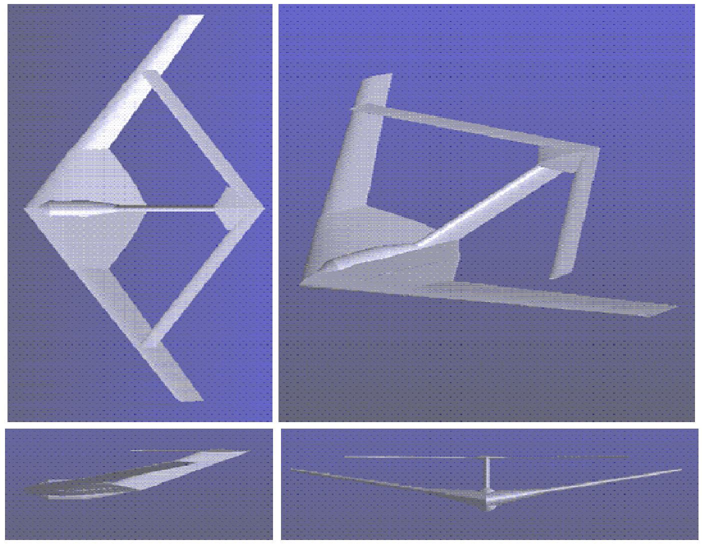


Figure 41 Surrogate ACSYNT Input Model

ACSYNT is also unable to model wing twist, other than linear t/c and chord distributions, and outboard wing sweep. The fuselage is modeled in ACYSNT as a $FUS object, a constant cross section circular cylinder with a tapered nose cone and tail cone (fig. 42). The fuselage diameter chosen is the overall fuselage height of the CAD model of 8.82 ft, with fineness ratios (length/diameter) for the forward and aft section defined as inputs into ACSYNT.

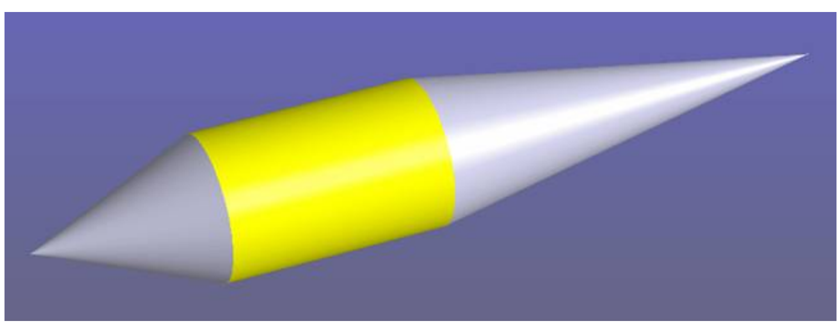


Figure 42 Simplified Fuselage with Constant Cross Section

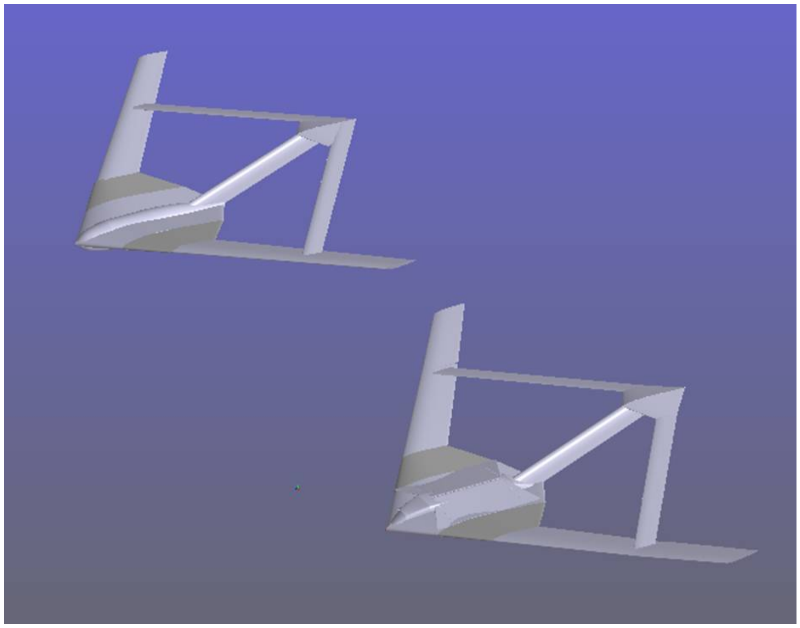


Figure 43 Comparison of Surrogate (left) and Original (right) Models

Trajectory/Mission

The required mission profile as given in table 2, requires a loiter of 12.6 hours and a 3000 nm RoA. This was duplicated in ACSYNT with the exception of the descent/climb prior to loiter, the division of the climb leg into three sublegs (ACSYNT constraint as climb legs of more than 20K ft cause errors) and a descent credit of 80 nm (ACSYNT default setting). A design load factor of 2 was applied (ref. 21).

Propulsion

From Boeing's propulsion data (ref. 21) the it was determined the design includes two turbofan engines with a bypass ratio of 5, maximum sea-level static thrust of 30000 lbs per engine, and a total propulsion weight of 11977 lbs, to include fuel system. This was modeled in ACYSNT by applying an engine scaling factor (ESF) to drive the thrust to 30000 lbs for the high bypass turbofan (JY-9D), (4) of Table 6, and the BPR was

modified as well. Lastly, a propulsion weight scaling factor was used to fix the baseline weight at 11977 lbs for the entire propulsion system, comprising engines and fuel system.

Aerodynamics

The AEI report (ref. 21) showed laminar flow over nearly 40% of the wing surface and this was modeled in ACSYNT by changing the default value of the laminar to turbulent flow factor (SFWF variable in the $ACHAR namelist) to reflect a conservative value of 0.63, or 37% laminar flow. Appendix H shows the effect of varying this parameter for the baseline model in ACSYNT. The AEI report (ref. 21) also showed a C_{L0} of approximately 0.4, which was used as well.

Weights

To adjust the ACSYNT output component weights to the FEM measured structural weights (ref. 21), in order to get an accurate prediction of fuel usage, the baseline model was run once to determine the adjustments required. Through an iterative procedure, as each variable affects the others, each variable was adjusted until it agreed with the FEM 410E model within 1.00%.

Table 17 Detail of ACSYNT Model Weight Slopes

Component	Unweighted	Desired	1st Slope	Final Slope	Actual	Difference
Wing	34278	7652	0.223	0.237	7643	0.12%
Fuselage	3128	6460	2.065	2.110	6460	0.00%
Horiz. Tail	5783	4113	0.711	0.750	4142	0.71%
Vert. Tail	3103	1238	0.399	0.420	1245	0.57%
Nacelle	2743	866	0.316	0.315	864	0.23%
Landing Gear	5200	3858	0.742	0.800	3853	0.13%
APU	610	864	1.416	1.426	868	0.46%
Electrical	2310	1064	0.461	0.520	1070	0.56%
Control Surf.	2616	1199	0.458	0.458	1198	0.08%

Unweighted means the baseline 410E model run through ACSYNT with no fixed

or weighted values and default parameters: half-wing span (b) = 75, leading-edge front wing sweep (Λ_{ib}) = 38 deg, trailing edge aft wing sweep (Λ_{ia}) = 38 deg, leading-edge outboard wing sweep (Λ_{ob}) = 38 deg, joint location as a percentage of half span (j_{loc}) = 0.7117, vertical offset of the aft-wing root (z_{fa}) = 16.13 ft and airfoil thickness to chord ratio (t/c) = 0.08.

Desired represents the desired weight to match the 410E Model Structural weights as given in ref. 21. ACSYNT uses slope values to increase or reduce certain weights in order to match a given aircraft. The first slope represents the initial guess of desired over unweighted. The final slope is what was used to determine the actual ACSYNT output weights, which are given in column 6 of Table 17.

ACSYNT sizing

The Joined wing model was not sized by initial or refined methods due to their reliance on historical data. ACSYNT results for the baseline model (all variables default) show good correlation with the available Boeing AEI data. There is no fuel weight or TOGW given for the 410E model in the AEI report (ref.21), and nor is there an empty weight given for the 410D model. The finite element model contains point masses for fuel weight, but there is no indication as to what point of the mission those values are valid. Also two different values are given for the 410E structural data, one of 22851 lbs is included in the overall empty weight buildup (table 3) and the other of 26124 lbs is derived from the structural component weight buildup (table 4). For the purpose of this study a target structural weight value of 24187 was used, which is between the high and low values of the Model 410E data and on par with the 410D data.

Table 18 Joined Wing Weights Comparison

	Boeing Model (410D) (baseline)	Boeing Model (410E) (optimized)	ModelCenter (410E)	Model percent difference from baseline
Structural Weight	24572	22851 /26124	24161	1.67%
Payload Weight	8860	8861	8862	0.02%
Empty Weight	~49000*	50674	41404	15.50%
ToC Weight	109570	112000	109281	0.26%
Fuel Weight	65000	~60000*	62003	4.61%
Take-off Gross Weight (TOGW)	114630	~111000*	112369	1.97%
* values starred represent best guess due to absence of explicit data				

FEM manipulation

The joined-wing model was broken up into six different sections to enable modification and perturbation of the Boeing 410E Finite Element Model (FEM) as shown in figure 44, variables are shown pictorially in figure 3..

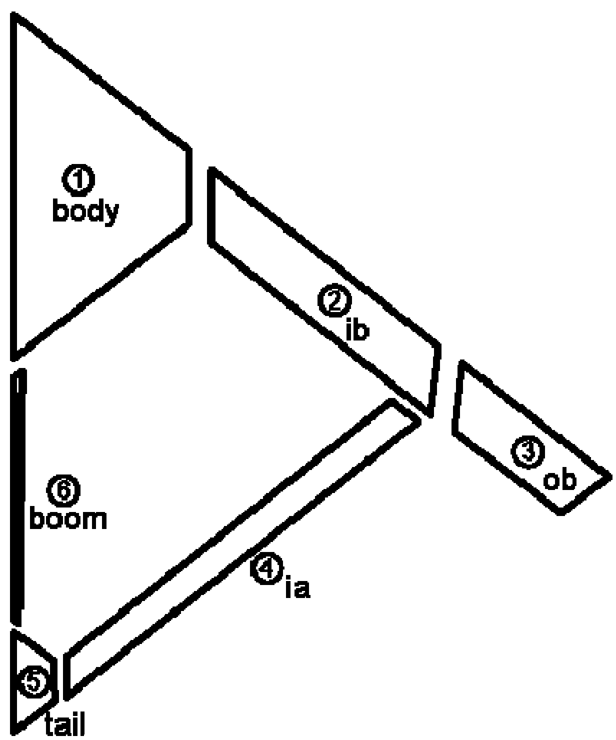


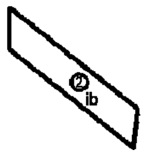
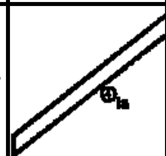
Figure 44 Joined Wing Finite Element Model Sections

Each FEM point in each section has associated x, y, z GRID coordinates and equations were written to modify the coordinates in each section based on a change to the initial design variables. Coded in MATLAB, (App. F) the following table depicts the effect of a change to each coordinate in each section by individual variable change. If multiple variables are changed, they are calculated in sequential order, with the new output coordinates assuming the role of the initial coordinates for the next equation. Equations display delta values which can be used with eqn. (14) to determine the new values.

$$X = \Delta X + X' \tag{14}$$

where X is the new coordinate of interest, ΔX is the change in the original value, and X' is the original value.

Table 19 FEM Manipulation Equations Matrix

Section			Variables						
Name	Area		b	Λ_{ib}	Λ_{ob}	Λ_{ia}	z_{fa}	t/c	j_{loc}
(1) Body		**Δx =**		**(17)**					
		Δy =							
		Δz =	**(27)**				**(28)**		**(27)**
(2) Inboard Front Wing (ib)		**Δx =**	**(19)**	**(17)**					**(23)**
		Δy =	**(20)**						**(24)**
		Δz =	**(29)**				**(28)**	**(38)**	**(29)**
(3) Outboard Front Wing (ob)		**Δx =**	**(21)**	**(18)**	**(18)**				**(25)**
		Δy =	**(22)**						**(26)**
		Δz =					**(28)**	**(38)**	
(4) Aft Wing (ia)		**Δx =**	**(32)**	**(18)**		**(34)**			**(32)**
		Δy =	**(33)**						**(33)**
		Δz =	**(29)**				**(35)**	**(39)**	**(29)**
(5) Tail		**Δx =**	**(32)**	**(31)**		**(34)**			**(32)**
		Δy =	**(33)**						**(33)**
		Δz =	**(29)**				**(35)**		**(29)**
(6) Boom		**Δx =**	**(36)**	**(36)**		**(36)**			**(36)**
		Δy =							
		Δz =		**(37)**		**(37)**	**(37)**		**(37)**
Numbers in table map to equation numbers.									

where b is half-wingspan, l_{boom} is current boom length, l_{body} is body or fuselage length, w_{body} is width of body or fuselage,

$$b_{ib} = j_{loc} * b \qquad (15)$$

$$b_{ob} = b(1 - j_{loc}) \qquad (16)$$

$$\Delta x = y'\left[\tan(\Lambda_{ib}) - (\tan(\Lambda_{ib}')\right] \tag{17}$$

$$\Delta x = b_{ib}'\left[\tan(\Lambda_{ib}) - (\tan(\Lambda_{ib}')\right] + (y' - b_{ib}')\left[\tan(\Lambda_{ob}) - (\tan(\Lambda_{ob}')\right] \tag{18}$$

$$\Delta y = \frac{y'}{j_{loc}}(j_{loc} - j_{loc}')\tan(\Lambda_{ib}) \tag{19}$$

$$\Delta y = (b_{ib} - b_{ib}')\left(\frac{y' - w_{body}}{b_{ib}' - w_{body}}\right) \tag{20}$$

$$\Delta x = \left[\tan(\Lambda_{ib})(b_{ib} - b_{ib}') - (\tan(\Lambda_{ob})(b_{ib} - b_{ib}')\right]\left(\frac{\frac{y'}{b'} - j_{loc}}{1 - j_{loc}}\right) \tag{21}$$

$$\Delta y = (b_{ib} - b_{ib}')\left(1 + \frac{\frac{y'}{b'} - j_{loc}'}{1 - j_{loc}'}\right) \tag{22}$$

$$\Delta x = (b_{ib} - b_{ib}')\frac{y' - w_{body}}{b_{ib}' - w_{body}}\tan(\Lambda_{ib}) \tag{23}$$

$$\Delta y = \frac{y'}{j_{loc}}(j_{loc} - j_{loc}') \tag{24}$$

$$\Delta x = b'(j_{loc} - j_{loc}')\tan(\Lambda_{ib}) + b'(2 - j_{loc} + j_{loc}')\tan(\Lambda_{ob}) \tag{25}$$

$$\Delta y = \frac{b' - y'}{1 - j_{loc}}(j_{loc} - j_{loc}') \tag{26}$$

$$\Delta z = y'\left(\frac{z_{fa}'}{2}\right)\left(\frac{1}{b_{ib}} - \frac{1}{b_{ib}'}\right) \tag{27}$$

$$\Delta z = y'\left(\frac{z_{fa} - z_{fa}'}{2b_{ib}'}\right) \tag{28}$$

$$\Delta z=\left(\frac{z_{fa}}{2}\right)\left(\frac{w_{body}}{b_{ib}}+\left(\frac{y'-w_{body}}{b_{ib}'-w_{body}}\right)\left(\frac{j_{loc}-w_{body}}{b_{ib}}\right)\right)$$
$$-\left(\frac{z_{fa}'}{2}\right)\left(\frac{w_{body}}{b_{ib}'}+\left(\frac{y'-w_{body}}{b_{ib}'-w_{body}}\right)\left(\frac{j_{loc}'-w_{body}}{b_{ib}'}\right)\right) \quad (29)$$

$$\Delta z=\left(\frac{y'-b_{ib}'}{b'-b_{ib}'}\right)\left(\frac{z_{fa}}{2\,j_{loc}}\right)-\left(\frac{y'-b_{ib}'}{b'-b_{ib}'}\right)\left(\frac{z_{fa}'}{2\,j_{loc}}\right) \quad (30)$$

$$\Delta x=b_{ib}'\left(\tan(\Lambda_{ib})-\tan(\Lambda_{ib}')\right) \quad (31)$$

$$\Delta x=\left(b_{ib}-b_{ib}'\right)\tan(\Lambda_{ib})+\left(b_{ib}-b_{ib}'\right)\left(\frac{b_{ib}-y'}{b_{ib}'}\right) \quad (32)$$

$$\Delta y=\frac{y'}{b_{ib}'}\left(b_{ib}-b_{ib}'\right) \quad (33)$$

$$\Delta x=\left(b_{ib}-y'\right)(\tan(\Lambda_{ia})-\tan(\Lambda_{ia}')) \quad (34)$$

$$\Delta z=\frac{(z_{fa}-z_{fa}')}{2}\left(1+\frac{b_{ib}'-y'}{b_{ib}'}\right) \quad (35)$$

$$\Delta x=\frac{z'}{z_{fa}}\left[b_{ib}\left(\tan(\Lambda_{ib})+\tan(\Lambda_{ia})\right)-b_{ib}'\left(\tan(\Lambda_{ib}')+\tan(\Lambda_{ia}')\right)\right] \quad (36)$$

$$\Delta z=\frac{x'-l_{body}}{b_{ib}\left(\tan(\Lambda_{ib})+\tan(\Lambda_{ia})\right)-l_{body}}\left(z_{fa}-z_{fa}'\right) \quad (37)$$

$$\Delta z=z'-\left(\frac{y'}{b_{ib}}\right)\left(\frac{z_{fa}'}{2}\right)\left(\frac{t/c}{t/c'}\right) \quad (38)$$

$$\Delta z=\left[z'-\left(\left(\frac{z_{fa}'}{2}\right)+\left(\frac{z_{fa}'}{2}\right)\left(\frac{b_{ib}-y'}{b_{ib}}\right)\right)\right]\left(\frac{t/c}{t/c'}\right) \quad (39)$$

Although a structural optimization was not accomplished on the joined-wing SensorCraft model, the all the pieces are in place in order to conduct one. From the joined wing FEM input (*jw.dat*) GRID data (*xyz.txt*), presorted by part, is extracted with an include reference to the *xyz.txt* file. The *xyz.txt* file is then read into MATLAB by way of *readxyz.m*, and coordinates are transformed according the *modxyz.m* script, which links to ModelCenter for required variables and output back to the original *xyz.txt* file. Then using a simple filewrapper, ModelCenter can execute a NASTRAN run and parse the output file (jw.f06) for the structural weight data to include in the joined-wing model.

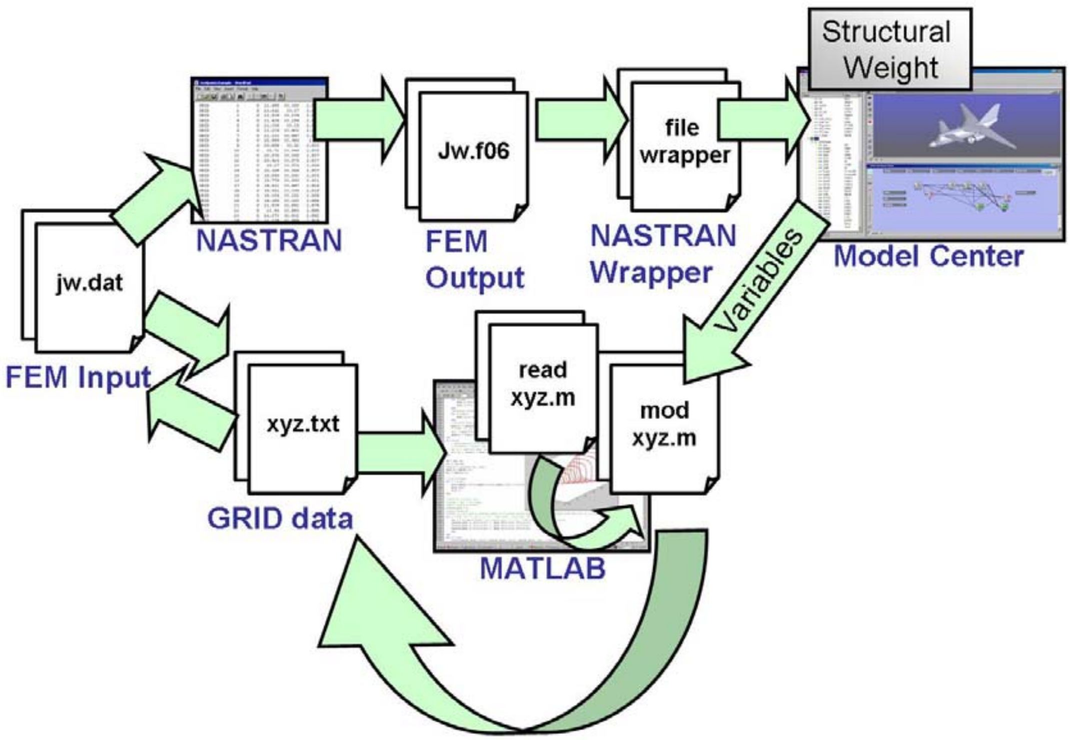


Figure 45 ModelCenter Structural Weight Incorporation

Design Variables

The design variables (fig. 3) are: overall wing span (b), front wing sweep (Λ_{ib}), aft wing sweep (Λ_{ia}), outboard wing sweep (Λ_{ob}), joint location as a percentage of half span (j_{loc}), vertical offset of the aft-wing root (z_{fa}) and airfoil thickness to chord ratio (t/c).

Design of Experiments (DOE)

A design of experiments (DOE) table was built in ModelCenter, to vary the seven design variables ± 10% about the Boeing solution. A 100-step Latin-squares DOE (100 runs) was utilized, which executed in about 30 minutes. For comparison, a Central Composite DOE (143 runs), and a 3-step full factorial DOE were also constructed. The Central Composite DOE executed in about 60 minutes, and the full factorial required about 10 hours to complete the 2187 runs.

Sensitivity Analysis

From the Latin-squares DOE data, a variable sensitivity analysis (effect on TOGW) was conducted on the design variables. Results showed that the main effects on TOGW were inboard wing sweep (Λ_{ib}) which accounts for nearly half (49%) of the objective response, with vertical offset (z_{fa}) and half-wing span (b) accounting for another 20% each. Previous studies [19] have shown a similar correlation between modifying vertical offset and inboard sweep, and span was expected to have a significant part in the response of the total weight. As expected modifications of outboard wing sweep (Λ_{ob}) had no effect on the TOGW, due to the modeling limitations of a sweeping outer wing in ACSYNT. Thickness-to-chord (t/c) and aft wing sweep (Λ_{ia}) had little effect on the

design, presumably because the changes resulted in no major aerodynamic effects and areas affected were small compared with the forward wing or fuselage.

After a critical review of the initial data from the Latin-squares DOE, a sensitivity analysis was also performed for the larger full-factorial DOE (2817 runs). This new study showed drastically different results (fig. 46), primarily due to a better characterization of the design space. The main effect shown is the half wing span (b), followed by joint location (j_{loc}), inboard sweep (Λ_{ib}) and vertical offset (z_{fa}). Outboard sweep as expected showed no effect on the TOGW as expected, and the other two variables showed minimal impact.

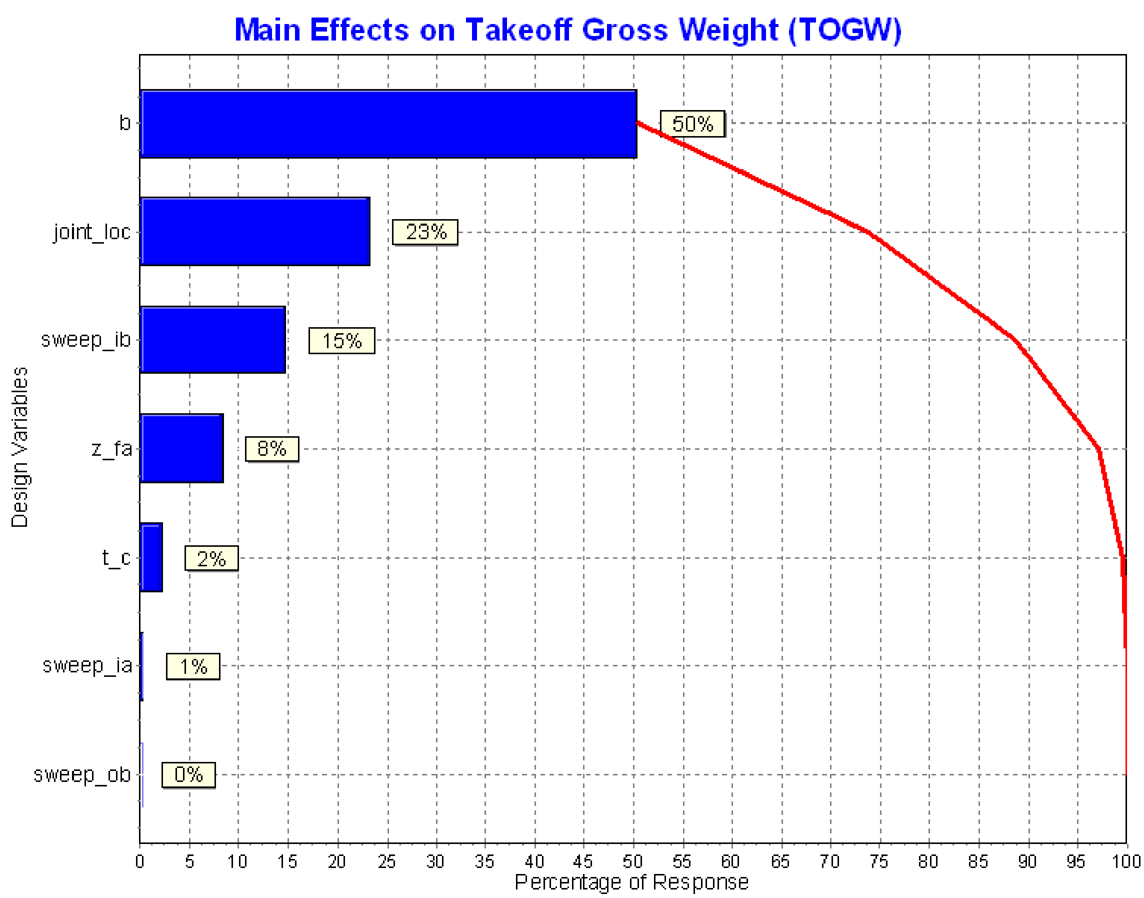


Figure 46 Variable Sensitivity Analysis

Joined-Wing Response Surfaces

The purpose of response surfaces is to approximate complex relationships with fast running surrogate equations in order to reduce the design space exploration time and enable faster optimization. The optimization toolkit currently in ModelCenter is not licensed and an optimization was not possible by that means. However from observing the trends and parameter interaction as a result of running the DOE and from investigating the response surface data, a vector toward a lower weight solution can be established.

The Design of Experiments (DOE) tool was used to populate the DataCollector, and then response surface models were created using the RSMToolkit, a Java and FORTRAN90 based software tool. This response surface model then approximates the GTOW over some range of the input variables, which can be used in conjunction with an optimizer to perform a rapid design study. Highlight of the response surface Standard Analysis of Variance (ANOVA) table for GTOW data is listed in appendix G, plots of significant variable interaction are given in appendix B.

Some relevant statistics on the response surface model created are the standard error of 2566 lbs, the average response of 115189 lbs, the coefficient of variation (COV) of 2.23% , the ratio of the standard error to the average response and the R^2 value of 79.72.%, which can be thought of as the percentage of the total variability of the data which is explained by the response surface approximation. The R^2(adj.) value of 78.54% is close to the R^2 value which indicates the response surface is not overfitted, and should be usable for prediction. The fit is not terribly accurate, but provides a good starting

point for further design optimization. For a better fitting response surface, a larger DOE should be conducted and outliers (points with a standardized residual (StdR) greater than 3), should be investigated to see if they are inaccurate, and if they are errant removed from the fit.

V. Conclusions and Recommendations

The finite element modeling of structures is becoming more necessary for advanced non-conventional structural weight prediction. Historical methods are insufficient for estimation of novel designs. Integrated finite element analysis and optimization, which incorporates the non-linear aeroelastic effects of the joined-wing design for the critical load cases will be the beginning of the successful pursuit of an efficient and safe joined wing design, and the seed for the next generation of revolutionary design concepts.

Although not completed in this study, the template environment and linkages to integrated finite element optimization was achieved through the use of ModelCenter as an integration environment. The model can be expanded to include other codes and aerodynamic calculations.

ACSYNT was proven as a powerful, but testy and unpredictable tool for the calculation of component weights for conventional designs. The main drawbacks to its use in a classroom environment are the lengthy learning time, the lack of good documentation, and the dearth of technical support, as the program is no longer supported by the vendor. For the power user, who has a thorough understanding of all of the variables and drill-down access to the code, it will continue to be an excellent tool for the sizing and performance predication of conventional craft. Its limitations though in duplicating the design of an unconventional aircraft such as the joined-wing SensorCraft are serious. ACSYNT would be a much more valuable tool in modeling unconventional

designs if it were able to create multiple $WING objects and a variety of $FUS objects, with varying cross-sectional shapes.

ModelCenter is an excellent integration environment, with seemingly endless expansion capability. The built-in toolkits for the Design of Experiments (DOE) and Response Surface Models are excellent, as well as the data viewing application Data Explorer. Weaknesses in modeling aircraft structures still remain. The inability to create a wing from airfoil shapes, a twist and thickness schedule, prevents the use of the NURBS rendered surfaces as more than cosmetic. Further integration attempts with CAD software like Catia would prove useful for more accurate geometry determination, and provide a handoff point for conceptual designs to the preliminary design teams in the industry standard. Boeing’s General Geometry Generator looks promising, especially for the rapid population of radical new designs, although the Python coding obstacle still presents a challenge. Future integration within ModelCenter should be explored however, especially as it concerns the development of meshes and grids for CFD and finite element analysis

Advanced component geometry with integrated surface/volume calculation would also provide a sleeker interface for the construction and maintenance of models. This would also require a significant amount of coding and learning of Java. Should this be accomplished it would be possible to integrate airfoil shapes into the wing, and possibly to integrate 2-D foil generation software and aerodynamic calculations directly into the model.

Considerations for stealthy and survivable design could also be pursued as a welcome addition to the joined wing model. The integration of survivability concerns early in the conceptual design phase prevents expensive redesign at a later stage.

Stability and control calculations were made for a radio controlled joined- wing model [29], which could be compared to analytical calculations for the Boeing model and integrated into ModelCenter. Initial experimental wind tunnel testing on the Boeing joined-wing 410E model was also conducted [30] determining forces and moments required for pitch control. Aeroelastic response will be investigated in follow-on testing. This experimental data should be incorporated into the ModelCenter joined wing model.

Lastly, a Life Cycle Cost (LCC) model should be built and integrated in ModelCenter with LCC set as a competing objective function to TOGW. This could provide insight into multi-objective optimization for the joined-wing SensorCraft and lead to a lower overall cost to the taxpayer, at the right level of performance.

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Appendix A: ACSYNT Files

A-1 Canarded ASW Aircraft (Mission2-HI_HI_HI).IN
A-2 Canarded ASW Aircraft (Mission2-HI_HI_HI).OUT

A-3 S-3 (Mission2-HI_HI_HI).IN
A-4 S-3 (Mission2-HI_HI_HI).OUT

A-5 S-3 (Mission1-HI_LO_HI).IN
A-6 S-3 (Mission1-HI_LO_HI).OUT

A-7 JW.IN
A-8 JW.OUT

A-1 Canarded ASW Aircraft (Mission2-HI_HI_HI).IN

```
TRANSPORT
    5    3    5  570  585    0    0    0    0    1    7    0
    0.0005      0.50 499000.00      0.00      0.00      0.00
    1    2    3    4    6
    1    2    6
    1    2    3    4    6
*** Geometry for Raymer ASW model***
$WING
   AR         =     9.059, AREA      =   510.415, DIHED     =    -4.0,
   LFLAPC     =     0.12, SWEEP     =    20.0, TAPER     =     0.25,
   TCROOT     =     0.17, TCTIP     =     0.12, TFLAPC    =     0.12,
   WFFRAC     =     1.0, XWING     =     0.65, ZROOT     =     0.75,
   KSWEEP     =         1, FDENWG    =    50.86, SWFACT    =     0.960,
$END
$STRAKE
   XLEXT      =     0.419, YSEXT     =     0.265, SLEXT     =    40.0,

$END
$VTAIL
   AR         =     1.026, AREA      =    97.5, SWEEP     =    45.0,
   TAPER      =     0.25, TCROOT    =     0.12, TCTIP     =     0.12,
   VTNO       =     1.0, XVTAIL    =     1.0, YROOT     =     0.0,
   ZROOT      =     1.0, KSWEEP    =         1, SIZIT     =   false,
   SWFACT     =     0.960,
$END
$CANARD
   AR         =     5.715, AREA      =   157.488, SWEEP     =    20.0,
   TAPER      =     0.43, TCROOT    =     0.12, TCTIP     =     0.12,
   XCAN       =     0.192, ZROOT     =     0, KSWEEP    =         1,
   SWFACT     =     0.960,
$END
$FPOD
   X          =     0.0, THETA  = 0.0, SOD = 0, SYMCOD = 0,
$END
$WPOD
   DIAM       =     4.5, LENGTH    =    10.8, X         =     0.256,
   Y          =     0.21, Z         =    -0.4, SWFACT    =     0.96,
   SYMCOD = 0,
$END
$FUS
   BDMAX      =     8.0, BODL      =    51.0, DRADAR    =     3.0,
   FRAB       =     2.04, FRATIO    =     0.0, FRN       =     1.148,
   LRADAR     =     4.0, SFFACT    =     1.0, THTAB     =    28.514,
   THTNOS     =    33.185, WFUEL     = 20000.0, ITAIL     =         1,
$END
$CREW
   NCREW   =           2,
$END
$ENGINE
   N          =         2,
$END
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$TRDATA
   CRMACH     =     0.6, DESLF     =     2.5, FRFURE    =     0.05,
   QMAX       =   500.0, RANGE     =  1500.0, TIMTO1    =     5.0,
   TIMTO2     =     0.5, WFEXT     =     0.0, WFTRAP    =   100.0,
   XDESC      =    80.0, IPSIZE    =        -3, IPRINT    =         1,
   IPSTO1     =         5, IPSTO2    =         2, MMPROP    =         1,
   NCODE      =         0,
$END
         6   0.0E+00
         MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  'G'S  WKFUEL M IP IX W B A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.00   -1      0 15000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.41 0.00  15000 30000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CRUISE   .60 0.00  30000 30000  1500.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
```

```
LOITER   .56 0.00  30000 30000     0.0 180.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
CRUISE   .60 0.00  35000    -1  1500.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
LOITER  0.56 0.00     -1     0     0.0  20.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
***** AERODYNAMICS *****
$ACHAR
   ABOSB     =     0.1, ALMAX     =    15.0, AMC       =    30.0,
   BDNOSE    =      7.0, BTEF      =     1.0, RCLMAX    =     1.5,
   ROC       =     0.02, ROCAN     =     0.02, SFWF      =     0.9,
   SMNDR     =     0.93, SPANAC    =    0.0, XCDC      =     0.6,
   XCDW      =     0.6, AJCAN     =         2, ALELJ     =         2,
   IDELTA    =         0, INORM     =         1, ISMNDR    =         0,
   ISUPCR    =         0, ITRAP     =         0, IXCD      =         1,
   ELLIPC    =   false, ELLIPH    =   false, ELLIPW    =   false,
   SMNSWP    =   0.1,  0.15,  0.2,  0.25,  0.35,  0.45,  0.5,  0.55,  0.6,  0.65,
   CLOW      =   0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
   CLOW      =   0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
   CLOC      =   0.05,  0.05,  0.05,  0.05,  0.05,  0.05,  0.05,  0.05,  0.05,  0.05,
$END
$AMULT
   CSF       =     1.0, ESSF      =     1.0, FCD       =     1.0,
   FCDF      =     1.0, FCDL      =     1.0, FCDW      =     1.0,
   FCDWB     =     1.0, FENG      =     1.0, FINTF     =     1.0,
   FLBCOR    =     1.0, FLECOR    =     1.0, FMDR      =     1.0,
$END
$ATRIM
   FVCAM =        1.0,     1.0,     1.0,     1.0,      1.0,    1.0,     1.0,     1.0,
1.0,     1.0,
   FLDM  =        1.0,     1.0,     1.0,     1.0,      1.0,    1.0,     1.0,     1.0,
1.0,     1.0,
   ITRIM =        0,     0,     0,     0,      0,    0,     0,     0,     0,     0,
   CAND      =     0.0, CFLAP     =     0.2, CGM       =     0.25,
   IT        =     0.0, SM        =     -0.15, SPANF     =     0.75,
   ZCG       =     0.0, IVCAM     =         1.0,
$END
$ADET
   IPLOT     =         1, NALF      =        10, NMDTL     =         8,
   ICOD      =         1,
   ALIN      =     -2.5,     0.0,     0.5,     1.0,     1.5,     2.0,     2.5,     3.0,
3.5,    4.0,
   ALTV      = 38000.0, 40000.0, 42000.0, 44000.0, 38000.0, 40000.0, 42000.0, 44000.0,
   SMN       = 0.56, 0.56, 0.56, 0.56, 0.6, 0.6, 0.6, 0.6,
   ISTRS     =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   ITB       =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   ITS       =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
$END
$ADRAG
   ICDO      =         0,
   CDBMB     =    10*0.0,
   CDEXTR    =    10*0.0,
   CDTNK     =    10*0.0,
$END
$ATAKE
   CLLAND    =        -1, CLTO      =        -1, DELFLD    =    35.0,
   DELFTO    =   25.0, DELLED    =    25.0, DELLTO    =    25.0,
   LDLAND    =        -1, LDTO      =        -1,
$END
$APRINT
   ECHOIN    =         1, ECHOUT    =         0, INTM      =         0,
   IPBLNT    =         0, IPCAN     =         0, IPENG     =         0,
   IPEXT     =         0, IPFLAP    =         0, IPFRIC    =         0,
   IPINTF    =         0, IPLIFT    =         0, IPMIN     =         0,
   IPWAVE    =         0, KERROR    =         0,
$END
*** Propulsion for ASW model SCALED (1.29) GE-TurboFan TF34-GE-2 turbofans, ~13950 lbf
each (M=0.6) ***
6
$LEWIS
  AENDIA =     4.167,  AENLE  =     8.33,  AENWT  =  1421.0, TWOAB = 13950,
$END
```

```
$AFTBD
$END
TRANSPORT
***** WEIGHTS *****
$OPTS
   WGTO      =50000.000, AFMACH    =     0.730, IDELT     =         1,
   KBODY     =         2,
   SLOPE     = 1,1,1,1,1, 1,1,1,1,1, 1,1,1,1,1, 1,1,1,1,1,
   TECHI     = 1,1,1,1,1,1,1,1,1,
$END
$FIXW
   WCREW    =    800.000, WELT      =   4353.000, WPA       =     0.001,
   WPASS    =      0.001, WBAG      =    100.000, WCARGO    =     0.001,

$END
```

A-2 Canarded ASW Aircraft (Mission2-HI_HI_HI).OUT

```
***** WEIGHTS *****

Qmax:                       500.
Design Load Factor:        2.50
Ultimate Load Factor:      3.75
Structure and Material:    Aluminum Skin, Stringer
Wing Equation:             Delta Wing Equation
Body Equation:             Air Force Equation

Component                            Pounds Kilograms Percent Slope Tech Fixed

Airframe Structure                    9637.    4371.  16.26              No
  Wing                                2356.    1069.   3.98  1.00  1.00  No
  Fuselage                            2567.    1164.   4.33  1.00  1.00  No
  Horizontal Tail   ( Low)              0.       0.   0.00  1.00  1.00  No
  Vertical Tail                        490.     222.   0.83  1.00  1.00  No
  Canard                               554.     251.   0.94  1.00  1.00  No
  Nacelles                             965.     438.   1.63  1.00  1.00  No
  Landing Gear                        2704.    1226.   4.56  1.00  1.00  No

Propulsion                            3695.    1676.   6.23              No
  Engines           (  2)             3410.    1547.   5.75  1.00  1.00  No
  Fuel System                          284.     129.   0.48  1.00  1.00  No

Fixed Equipment                       9592.    4351.  16.18        1.00  No
  Hyd & Pneumatic                      356.     161.   0.60  1.00        No
  Electrical                          1572.     713.   2.65  1.00        No
  Avionics                            4353.    1975.   7.34  1.00        Yes
  Instrumentation                      761.     345.   1.28  1.00        No
  De-ice & Air Cond                    246.     112.   0.41  1.00        No
  Aux Power System                     600.     272.   1.01  1.00        No
  Furnish & Eqpt                        0.       0.   0.00  1.00        Yes
    Seats and Lavatories                0.       0.   0.00  1.00        No
    Galley                              0.       0.   0.00  1.00        No
    Misc Cockpit                       234.     106.   0.40  1.00        No
    Cabin Finishing                    798.     362.   1.35  1.00        No
    Cabin Emergency Equip               0.       0.   0.00  1.00        No
    Cargo Handling                     348.     158.   0.59  1.00        No
  Flight Controls                     1705.     773.   2.88  1.00        No

Empty Weight                         22924.   10398.  38.67

Operating Items                       1067.     484.   1.80              No
  Flight Crew       (  2)              800.     363.   1.35              Yes
  Crew Baggage and Provisions          150.      68.   0.25              No
  Flight Attendents (  0)               0.       0.   0.00              No
  Unusable Fuel and Oil                100.      45.   0.17              No
  Passenger Service                     17.       8.   0.03              No
  Cargo Containers                      0.       0.   0.00              No

Operating Weight Empty               23991.   10882.  40.47

Fuel                                 35187.   15961.  59.36

Payload                                100.      45.   0.17              No
  Passengers        (  0)               0.       0.   0.00              Yes
  Baggage                              100.      45.   0.17              Yes
  Cargo                                 0.       0.   0.00              Yes
                                   -------- -------- ------
Calculated Weight                    59278.   26888. 100.00              No

Estimated  Weight                    59287.   26892.

Percent Error                                         -0.01
```

SUMMARY --- ACSYNT OUTPUT:

GENERAL		FUSELAGE				WING	CANARD	VTAIL
WG	59278.	LENGTH		51.0	AREA	510.4	157.5	97.5
W/S	116.1	DIAMETER		8.0	WETTED AREA	870.5	199.6	188.5
T/W	0.47	VOLUME		2036.7	SPAN	68.0	30.0	10.0
N(Z) ULT	3.8	WETTED AREA		1118.8	L.E. SWEEP	23.3	23.4	52.3
CREW	2.	FINENESS RATIO		6.4	C/4 SWEEP	20.0	20.0	45.0
PASENGERS	0.				ASPECT RATIO	9.06	5.72	1.03
					TAPER RATIO	0.25	0.43	0.25
ENGINE		WEIGHTS			T/C ROOT	0.17	0.12	0.12
					T/C TIP	0.12	0.12	0.12
NUMBER	2.		W	WG	ROOT CHORD	12.0	7.3	15.6
LENGTH	8.3	STRUCT.	9637.	16.3	TIP CHORD	3.0	3.2	3.9
DIAM.	5.0	PROPUL.	3695.	6.2	M.A. CHORD	8.4	5.5	10.9
WEIGHT	1421.0	FIX. EQ.	9592.	16.2	LOC. OF L.E.	30.1	9.8	35.4
TSLS	13950.	FUEL	35287.	59.5				
SFCSLS	0.36	PAYLOAD	100.	0.2				
		OPER IT	1067.	1.8				

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
TAKEOFF	0.00	0.	263.	5.5	1980.8				
CLIMB	0.41	15000.	490.	3.4	13.7	10.44	13293.7	0.541	141.4
CLIMB	0.52	30000.	695.	7.4	34.4	11.11	7652.7	0.607	119.6
CRUISE	0.60	31424.	13207.	246.9	1451.9	9.11	5164.3	0.574	148.7
LOITER	0.56	30000.	8158.	180.0	990.2	9.25	4827.5	0.563	138.2
CRUISE	0.60	35000.	10054.	260.2	1500.0	7.16	3959.9	0.567	125.8
LOITER	0.56	35000.	645.	20.0	107.6	7.58	3486.6	0.555	109.6
LANDING					4703.1				

Block Time = 12.057 hr

Block Range = 4097.9 nm

A-3 S-3 (Mission2-HI_HI_HI).IN

```
TRANSPORT
    5    3    5  570  585    0    0    0    0    1    7    0
    0.0001      0.75 100000.00      0.00      0.00      0.00
    1    2    3    4    6
    1    2    6
    1    2    3    4    6
*** Geometry for S-3A model***
$WING
   AR        =     7.750, AREA      =   598.000, DIHED     =    -4.000,
   LFLAPC    =     0.100, SWEEP     =    15.000, TAPER     =     0.250,
   TCROOT    =     0.163, TCTIP     =     0.120, TFLAPC    =     0.234,
   WFFRAC    =     0.578, XWING     =     0.398, ZROOT     =     0.628,
   FDENWG    =     50.00, OUTCOD    =         2, KSWEEP    =         1,
$END
$HTAIL
   AR        =     4.050, AREA      =   120.000, SWEEP     =    20.000,
   TAPER     =     0.430, TCROOT    =     0.090, TCTIP     =     0.090,
   XHTAIL    =     1.000, ZROOT     =     0.000, KSWEEP    =         1,
   OUTCOD    =         2, SIZIT     =     false,
$END
$VTAIL
   AR        =     1.435, AREA      =   129.000, SWEEP     =    38.500,
   TAPER     =     0.430, TCROOT    =     0.120, TCTIP     =     0.120,
   VTNO      =     1.000, XVTAIL    =     1.000, YROOT     =     0.000,
   ZROOT     =     1.093, KSWEEP    =         1, OUTCOD    =         2,
   SIZIT     =   false,
$END
$WPOD
   DIAM      =     0.000, LENGTH    =     0.000, X         =    -0.364,
   Y         =     0.226, Z         =    -0.885, SYMCOD    =         0,
   OUTCOD    =         2,
$END
$FUS
   BDMAX     =     7.750, BODL      =    49.250,  FRAB      =     5.033,
   FRN       =     1.022, WFUEL     =  13144.00,  ITAIL     =         1,
   OUTCOD    =         2, SFFACT    =      1.00,
$END
$CREW
   LENGTH    =    10.420, WIDTH     =     7.167,  NCREW   =         4,
   TAND      =     false, OUTCOD    =         2,
$END
$ELEC
   LENGTH    =     9.170,
$END
$FUEL
   FRAC      =     1.000, WFUEL     =0.000,  DEN     =        50.00,
   OUTCOD    =         2,
$END
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$TRDATA
   TIMTO1    =     5.000, FWGMAX    =     1.200, TIMTO2    =     1.000,
   QMAX      =   700.000, FRFURE    =     0.050, XDESC     =    40.000,
   DESLF     =     3.500, WKFUEL    =     1.000, CRMACH    =     0.590,
   RANGE     =  1500.000, WKLAND    =     0.570, WFUEL     =  13144.00,
   FLFAC     =     1.000, WFEXT     =     0.000, DECEL     =     0.250,
   WFTRAP    =   100.000, NCRUSE    =         2, IPSTO1    =         5,
   IPSTO2    =         2, IPSIZE    =        -3, IPRINT    =         0,
   KERROR    =         2, MMPROP    =         1,
$END
        8   0.0E+00
         MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME    TURN  'G'S  WKFUEL M IP IX W B A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
ACCEL   0.23 0.33      0   500     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CLIMB   0.33 0.44    500 15000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
ACCEL   0.44 0.59     -1 15000     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
```

```
CRUISE  0.59 0.59  15000    -1   635.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
LOITER  0.34 0.34    100   100     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
CLIMB   0.34 0.44     -1 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CRUISE  0.59 0.59  10000    -1   635.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
LOITER  0.34 0.34    100   100     0.0  20.0   0.0   0.0  1.0000 1  4  0 0 0 0 0

***** AERODYNAMICS *****
$ACHAR
   XCDW      =     0.600, AMC       =    40.000, SMNDR     =     0.93,
   BTEF      =     1.000, RCLMAX    =     1.000, ROC       =     0.02,
   SFWF      =     1.000, ALELJ     =         2, IDELTA    =        0,
   INORM     =         1, ISMNDR    =         0, ISUPCR    =        1,
   ITRAP     =         0, IXCD      =         1,
   ELLIPC    =     false, ELLIPH    =     false, ELLIPW    =   false,
   SMNSWP    =  0.000, 0.200, 0.400, 0.600, 0.800, 1.000, 1.200, 1.400, 1.600, 1.800,
   CLOW      =      0,      0,      0,      0,      0,      0,      0,      0,      0,      0,
   CMO       =      0,      0,      0,      0,      0,      0,      0,      0,      0,      0,
$END
$AMULT
   CSF       =     0.0, ESSF      =     1.0, FCD       =     1.0,
   FCDF      =    0.95, FCDL      =     1.0, FCDW      =     1.0,
   FCDWB     =     1.0, FENG      =     1.0, FINTF     =     1.0,
   FLBCOR    =     1.0, FLECOR    =     1.0, FMDR      =     1.0,
$END
$ATRIM
   FVCAM     =       1,      1,      1,      1,      1,    1,      1,      1,      1,      1,
   FLDM      =       1,      1,      1,      1,      1,    1,      1,      1,      1,      1,
   ITRIM     =       1,      1,      1,      1,      1,    1,      0,      0,      0,      0,
   CFLAP     =     0.2, CGM       =     0.25,  IT        =     0.0,
   SM        =     0.1, SPANF     =     0.75,  ZCG       =     0.0,
   IVCAM     =       1,
$END
$ADET
   IPLOT     =         1, NALF      =        10, NMDTL     =        6,
   ICOD      =         1,
   ALIN      =     0.0,      0.5,      1.0,      1.5,      2.0,      4.0,      6.0,      8.0,
10.0,    12.0,
   ALTV      =  1000.0,  5000.0, 10000.0, 15000.0, 15000.0,   100.0,
   SMN       =    0.33,    0.34,    0.35,    0.44,    0.59,    0.34,
   ISTRS     =     0,      0,      0,      0,      0,      0,      0,      0,      0,      0,
   ITB       =     0,      0,      0,      0,      0,      0,      0,      0,      0,      0,
   ITS       =     0,      0,      0,      0,      0,      0,      0,      0,      0,      0,
$END
$ADRAG
   ICDO      =         0,
   CDBMB     =    10*0.0,
   CDEXTR    =    10*0.0,
   CDTNK     =    10*0.0,
$END
$ATAKE
   CLLAND    =        -1, CLTO      =        -1, DELFLD    =    35.0,
   DELFTO    =      25.0, DELLED    =      25.0, DELLTO    =    25.0,
   LDLAND    =        -1, LDTO      =        -1,
$END
$APRINT
   ECHOIN    =         1, ECHOUT    =         0, INTM      =        0,
   IPBLNT    =         0, IPCAN     =         0, IPENG     =        0,
   IPEXT     =         0, IPFLAP    =         0, IPFRIC    =        0,
   IPINTF    =         0, IPLIFT    =         0, IPMIN     =        0,
   IPWAVE    =         0, KERROR    =         0,
$END
*** Propulsion for ASW model GE-TurboFan TF34-GE-2 turbofans, 9,275 lbf (41.26 kN) each
(M=0.6) ***
6
$LEWIS
  AENDIA =     4.167  AENLE  =     8.33  AENWT  =  1425.0
$END
$AFTBD
$END
```

```
TRANSPORT
***** WEIGHTS *****
$OPTS
   WGTO      =43000.000, AFMACH    =     0.700, IDELT     =         1,
   KBODY     =         2,
$END
$FIXW
   WBODY  =      5067,   WCREW  =       850,   WE     =      2951,
   WELT   =      4353,   WEP    =      1086,   WFS    =       346,
   WCA    =       300,   WGEAR  =      1144,   WHDP   =       389,
   WHT    =       769,   WINST  =       174,   WLG    =      1670,
   WNA    =       806,   WSC    =      1604,   WVT    =       585,
   WWING  =      4890,   WCARGO =      1417,   WAIRC  =       951,
$END
```

A-4 S-3 (Mission2-HI_HI_HI).OUT

```
 ***** WEIGHTS *****

Qmax:                     700.
Design Load Factor:      3.50
Ultimate Load Factor:    3.75
Structure and Material:  Aluminum Skin, Stringer
Wing Equation:           ______________________________
Body Equation:           Air Force Equation

Component                          Pounds Kilograms Percent Slope Tech Fixed

Airframe Structure                  13787.    6254.  26.52              No
  Wing                               4890.    2218.   9.41  1.00  1.00  Yes
  Fuselage                           5067.    2298.   9.75  1.00  1.00  Yes
  Horizontal Tail   ( Low)            769.     349.   1.48  1.00  1.00  Yes
  Vertical Tail                       585.     265.   1.13  1.00  1.00  Yes
  Nacelles                            806.     366.   1.55  1.00  1.00  Yes
  Landing Gear                       1670.     758.   3.21  1.00  1.00  Yes

Propulsion                           3297.    1496.   6.34              No
  Engines           (  2)            2951.    1339.   5.68  1.00  1.00  Yes
  Fuel System                         346.     157.   0.67  1.00  1.00  Yes

Fixed Equipment                     10009.    4540.  19.25        1.00  Yes
  Hyd & Pneumatic                     389.     176.   0.75  1.00        Yes
  Electrical                         1098.     498.   2.11  1.00        Yes
  Avionics                           4353.    1975.   8.37  1.00        Yes
  Instrumentation                     174.      79.   0.33  1.00        Yes
  De-ice & Air Cond                   951.     431.   1.83  1.00        Yes
  Aux Power System                   1144.     519.   2.20  1.00        Yes
  Furnish & Eqpt                        0.       0.   0.00  0.00        No
    Seats and Lavatories                0.       0.   0.00  0.00        No
    Galley                              0.       0.   0.00  0.00        No
    Misc Cockpit                        0.       0.   0.00  0.00        No
    Cabin Finishing                     0.       0.   0.00  0.00        No
    Cabin Emergency Equip               0.       0.   0.00  0.00        No
    Cargo Handling                      0.       0.   0.00  0.00        No
  Flight Controls                    1604.     728.   3.09  1.00        Yes

Empty Weight                        27093.   12289.  52.11

Operating Items                      1334.     605.   2.57              No
  Flight Crew       (  4)             850.     386.   1.63              Yes
  Crew Baggage and Provisions         200.      91.   0.38              No
  Flight Attendents (  0)               0.       0.   0.00              No
  Unusable Fuel and Oil               100.      45.   0.19              No
  Passenger Service                    34.      16.   0.07              No
  Cargo Containers                    149.      68.   0.29              No

Operating Weight Empty              28427.   12894.  54.68

Fuel                                22630.   10265.  43.53

Payload                               932.     423.   1.79              No
  Passengers        (  0)               0.       0.   0.00              No
  Baggage                               0.       0.   0.00              No
  Cargo                               932.     423.   1.79              Yes
                                 -------- -------- ------
Calculated Weight                   51988.   23582.  99.43              No

Estimated  Weight                   51988.   23582.

       Percent Error                                        0.00
```

```
SUMMARY --- ACSYNT OUTPUT:
_________________________________________________________________________________

    GENERAL            FUSELAGE                                WING   HTAIL  VTAIL
 WG      51988.   LENGTH          49.3   AREA          598.0  120.0  129.0
 W/S       86.9   DIAMETER         7.8   WETTED AREA  1042.4  241.0  259.9
 T/W       0.36   VOLUME        1413.5   SPAN           68.1   22.0   13.6
 N(Z) ULT  3.8    WETTED AREA    890.8   L.E. SWEEP     19.1   24.8   43.1
 CREW       4.    FINENESS RATIO   6.4   C/4 SWEEP      15.0   20.0   38.5
 PASENGERS  0.                           ASPECT RATIO   7.75   4.05   1.43
                                         TAPER RATIO    0.25   0.43   0.43
    ENGINE             WEIGHTS           T/C ROOT       0.16   0.09   0.12
                                         T/C TIP        0.12   0.09   0.12
 NUMBER     2.                 W     WG  ROOT CHORD     14.1    7.6   13.3
 LENGTH    8.3    STRUCT.  13787. 26.5   TIP CHORD       3.5    3.3    5.7
 DIAM.     4.0    PROPUL.   3297.  6.3   M.A. CHORD      9.8    5.7   10.0
 WEIGHT 1425.0    FIX. EQ. 10009. 19.3   LOC. OF L.E.   16.1   46.8   36.0
 TSLS    9300.    FUEL     22730. 43.7
 SFCSLS   0.36    PAYLOAD    932.  1.8
                  OPER IT   1334.  2.6

 MISSION SUMMARY

 PHASE    MACH     ALT    FUEL   TIME     DIST   L/D    THRUST   SFC       Q
 =======  ====  ======  ======  =====   ======  =====  =======  =====  ======
 TAKEOFF  0.00      0.    232.    6.0   3122.9
 CLIMB    0.54  15000.    417.    4.2     22.0  14.01   8389.9  0.601   247.1
 CLIMB    0.63  30000.    602.    9.0     54.8  15.16   5014.9  0.651   175.7
 CRUISE   0.60  33392.   7416.  243.2   1423.1  15.07   2964.7  0.570   139.8
 LOITER   0.69  30000.   6095.  180.0   1220.1  13.69   3163.1  0.642   209.8
 CRUISE   0.60  33957.   6272.  256.7   1500.0  14.22   2259.1  0.591   136.9
 LOITER   0.69  33957.    519.   20.0    133.2  12.65   2448.2  0.636   174.8
 LANDING                                3082.6

 Block Time  = 11.985 hr
 Block Range = 4353.4 nm
```

A-5 S-3 (Mission1 - HI_LO_HI).IN

```
TRANSPORT
    5    3    5  570  585    0    0    0    0    1    7    0
    0.0001      0.75 100000.00      0.00      0.00      0.00
    1    2    3    4    6
    1    2    6
    1    2    3    4    6
*** Geometry for S-3A model***
$WING
   AR        =      7.750, AREA      =   598.000, DIHED     =    -4.000,
   LFLAPC    =      0.100, SWEEP     =    15.000, TAPER     =     0.250,
   TCROOT    =      0.163, TCTIP     =     0.120, TFLAPC    =     0.234,
   WFFRAC    =      0.578, XWING     =     0.398, ZROOT     =     0.628,
   FDENWG    =      50.00, OUTCOD    =         2, KSWEEP    =         1,
$END
$HTAIL
   AR        =      4.050, AREA      =   120.000, SWEEP     =    20.000,
   TAPER     =      0.430, TCROOT    =     0.090, TCTIP     =     0.090,
   XHTAIL    =      1.000, ZROOT     =     0.000, KSWEEP    =         1,
   OUTCOD    =          2, SIZIT     =     false,
$END
$VTAIL
   AR        =      1.435, AREA      =   129.000, SWEEP     =    38.500,
   TAPER     =      0.430, TCROOT    =     0.120, TCTIP     =     0.120,
   VTNO      =      1.000, XVTAIL    =     1.000, YROOT     =     0.000,
   ZROOT     =      1.093, KSWEEP    =         1, OUTCOD    =         2,
   SIZIT     =    false,
$END
$WPOD
   DIAM      =      0.000, LENGTH    =     0.000, X         =    -0.364,
   Y         =      0.226, Z         =    -0.885, SYMCOD    =         0,
   OUTCOD    =          2,
$END
$FUS
   BDMAX     =      7.750, BODL      =    49.250,  FRAB      =     5.033,
   FRN       =      1.022, WFUEL     =  13144.00,  ITAIL     =         1,
   OUTCOD    =          2, SFFACT    =      1.00,
$END
$CREW
   LENGTH    =     10.420, WIDTH     =     7.167,  NCREW   =         4,
   TAND      =      false, OUTCOD    =         2,
$END
$ELEC
   LENGTH    =      9.170,
$END
$FUEL
   FRAC      =      1.000, WFUEL     =0.000,  DEN     =        50.00,
   OUTCOD    =          2,
$END
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$TRDATA
   TIMTO1    =      5.000, FWGMAX    =     1.200, TIMTO2    =     1.000,
   QMAX      =    700.000, FRFURE    =     0.050, XDESC     =    40.000,
   DESLF     =      3.500, WKFUEL    =     1.000, CRMACH    =     0.590,
   RANGE     =  1500.000, WKLAND    =     0.570, WFUEL     =  13144.00,
   FLFAC     =      1.000, WFEXT     =     0.000, DECEL     =     0.250,
   WFTRAP    =    100.000, NCRUSE    =         2, IPSTO1    =         5,
   IPSTO2    =          2, IPSIZE    =        -3, IPRINT    =         0,
   KERROR    =          2, MMPROP    =         1,
$END
        8   0.0E+00
         MACH NO.   ALTITUDE     HORIZONTAL     NO.  VIND
PHASE   START END  START  END    DIST  TIME    TURN  'G'S  WKFUEL M IP IX W B A P
------- ---- ----  ----- -----  ------ -----   ---- -----  ------ - -- -- - - - -
ACCEL   0.23 0.33      0   500     0.0   0.0    0.0   0.0  1.0000 1  3 -1 0 0 0 0
CLIMB   0.33 0.44    500 15000     0.0   0.0    0.0   0.0  1.0000 1  2 -1 0 0 0 0
ACCEL   0.44 0.59     -1 15000     0.0   0.0    0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.59 0.59  15000    -1   635.0   0.0    0.0   0.0  1.0000 1  4  0 0 0 0 0
```

```
LOITER  0.34 0.34    100   100     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
CLIMB   0.34 0.44     -1 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CRUISE  0.59 0.59  10000    -1   635.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
LOITER  0.34 0.34    100   100     0.0  20.0   0.0   0.0  1.0000 1  4  0 0 0 0 0

***** AERODYNAMICS *****
$ACHAR
   XCDW      =     0.600, AMC       =    40.000, SMNDR     =     0.93,
   BTEF      =     1.000, RCLMAX    =     1.000, ROC       =     0.02,
   SFWF      =     1.000, ALELJ     =         2, IDELTA    =        0,
   INORM     =         1, ISMNDR    =         0, ISUPCR    =        1,
   ITRAP     =         0, IXCD      =        1,
   ELLIPC    =     false, ELLIPH    =     false, ELLIPW    =   false,
   SMNSWP    =  0.000, 0.200, 0.400, 0.600, 0.800, 1.000, 1.200, 1.400, 1.600, 1.800,
   CLOW      =      0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   CMO       =      0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
$END
$AMULT
   CSF       =     0.0, ESSF      =     1.0, FCD       =     1.0,
   FCDF      =    0.95, FCDL      =     1.0, FCDW      =     1.0,
   FCDWB     =     1.0, FENG      =     1.0, FINTF     =     1.0,
   FLBCOR    =     1.0, FLECOR    =     1.0, FMDR      =     1.0,
$END
$ATRIM
   FVCAM     =       1,     1,     1,     1,      1,    1,     1,     1,     1,     1,
   FLDM      =       1,     1,     1,     1,      1,    1,     1,     1,     1,     1,
   ITRIM     =       1,     1,     1,     1,      1,    1,     0,     0,     0,     0,
   CFLAP     =     0.2, CGM       =     0.25,  IT        =     0.0,
   SM        =     0.1, SPANF     =     0.75,  ZCG       =     0.0,
   IVCAM     =       1,
$END
$ADET
   IPLOT     =         1, NALF      =        10, NMDTL     =         6,
   ICOD      =         1,
   ALIN      =     0.0,     0.5,     1.0,     1.5,     2.0,     4.0,     6.0,     8.0,
10.0,    12.0,
   ALTV      =  1000.0,  5000.0, 10000.0, 15000.0, 15000.0,   100.0,
   SMN       =    0.33,    0.34,    0.35,    0.44,    0.59,    0.34,
   ISTRS     =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   ITB       =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   ITS       =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
$END
$ADRAG
   ICDO      =         0,
   CDBMB     =    10*0.0,
   CDEXTR    =    10*0.0,
   CDTNK     =    10*0.0,
$END
$ATAKE
   CLLAND    =        -1, CLTO      =        -1, DELFLD    =    35.0,
   DELFTO    =      25.0, DELLED    =      25.0, DELLTO    =    25.0,
   LDLAND    =        -1, LDTO      =        -1,
$END
$APRINT
   ECHOIN    =         1, ECHOUT    =         0, INTM      =         0,
   IPBLNT    =         0, IPCAN     =         0, IPENG     =         0,
   IPEXT     =         0, IPFLAP    =         0, IPFRIC    =         0,
   IPINTF    =         0, IPLIFT    =         0, IPMIN     =         0,
   IPWAVE    =         0, KERROR    =         0,
$END
*** Propulsion for ASW model GE-TurboFan TF34-GE-2 turbofans, 9,275 lbf (41.26 kN) each
(M=0.6) ***
6
$LEWIS
  AENDIA =     4.167  AENLE  =     8.33  AENWT  =  1425.0
$END
$AFTBD
$END
TRANSPORT
```

```
***** WEIGHTS *****
$OPTS
   WGTO      =43000.000, AFMACH    =     0.700, IDELT     =         1,
   KBODY     =        2,
$END
$FIXW
   WBODY  =      5067,   WCREW  =       850,   WE     =      2951,
   WELT   =      4353,   WEP    =      1086,   WFS    =       346,
   WCA    =       300,   WGEAR  =      1144,   WHDP   =       389,
   WHT    =       769,   WINST  =       174,   WLG    =      1670,
   WNA    =       806,   WSC    =      1604,   WVT    =       585,
   WWING  =      4890,   WCARGO =      1417,   WAIRC  =       951,
$END
```

A-6 S-3 (Mission1 - HI_LO_HI).OUT

```
 ***** WEIGHTS *****

Qmax:                       700.
Design Load Factor:        3.50
Ultimate Load Factor:      3.75
Structure and Material:    Aluminum Skin, Stringer
Wing Equation:             ______________________________
Body Equation:             Air Force Equation

Component                             Pounds Kilograms Percent Slope Tech Fixed

Airframe Structure                     13787.    6254.  31.12              No
  Wing                                  4890.    2218.  11.04  1.00  1.00  Yes
  Fuselage                              5067.    2298.  11.44  1.00  1.00  Yes
  Horizontal Tail   ( Low)               769.     349.   1.74  1.00  1.00  Yes
  Vertical Tail                          585.     265.   1.32  1.00  1.00  Yes
  Nacelles                               806.     366.   1.82  1.00  1.00  Yes
  Landing Gear                          1670.     758.   3.77  1.00  1.00  Yes

Propulsion                              3297.    1496.   7.44              No
  Engines           (  2)               2951.    1339.   6.66  1.00  1.00  Yes
  Fuel System                            346.     157.   0.78  1.00  1.00  Yes

Fixed Equipment                        10009.    4540.  22.59        1.00  Yes
  Hyd & Pneumatic                        389.     176.   0.88  1.00        Yes
  Electrical                            1098.     498.   2.48  1.00        Yes
  Avionics                              4353.    1975.   9.83  1.00        Yes
  Instrumentation                        174.      79.   0.39  1.00        Yes
  De-ice & Air Cond                      951.     431.   2.15  1.00        Yes
  Aux Power System                      1144.     519.   2.58  1.00        Yes
  Furnish & Eqpt                           0.       0.   0.00  0.00        No
    Seats and Lavatories                   0.       0.   0.00  0.00        No
    Galley                                 0.       0.   0.00  0.00        No
    Misc Cockpit                           0.       0.   0.00  0.00        No
    Cabin Finishing                        0.       0.   0.00  0.00        No
    Cabin Emergency Equip                  0.       0.   0.00  0.00        No
    Cargo Handling                         0.       0.   0.00  0.00        No
  Flight Controls                       1604.     728.   3.62  1.00        Yes

Empty Weight                           27093.   12289.  61.15

Operating Items                         1244.     564.   2.81              No
  Flight Crew       (  4)                850.     386.   1.92              Yes
  Crew Baggage and Provisions            125.      57.   0.28              No
  Flight Attendents (  0)                  0.       0.   0.00              No
  Unusable Fuel and Oil                  100.      45.   0.23              No
  Passenger Service                        2.       1.   0.01              No
  Cargo Containers                       166.      75.   0.38              No

Operating Weight Empty                 28337.   12854.  63.96

Fuel                                   14930.    6772.  33.70

Payload                                 1039.     471.   2.35              No
  Passengers        (  0)                  0.       0.   0.00              No
  Baggage                                  0.       0.   0.00              No
  Cargo                                 1039.     471.   2.35              Yes
                                    -------- -------- ------
Calculated Weight                      44305.   20097.  99.33              No

Estimated  Weight                      44305.   20097.

Percent Error                                            0.00
```

SUMMARY --- ACSYNT OUTPUT:

GENERAL

WG	44305.
W/S	74.1
T/W	0.42
N(Z) ULT	3.8
CREW	4.
PASENGERS	0.

FUSELAGE

LENGTH	49.3
DIAMETER	7.8
VOLUME	1413.5
WETTED AREA	890.8
FINENESS RATIO	6.4

	WING	HTAIL	VTAIL
AREA	598.0	120.0	129.0
WETTED AREA	1042.4	241.0	259.9
SPAN	68.1	22.0	13.6
L.E. SWEEP	19.1	24.8	43.1
C/4 SWEEP	15.0	20.0	38.5
ASPECT RATIO	7.75	4.05	1.43
TAPER RATIO	0.25	0.43	0.43
T/C ROOT	0.16	0.09	0.12
T/C TIP	0.12	0.09	0.12
ROOT CHORD	14.1	7.6	13.3
TIP CHORD	3.5	3.3	5.7
M.A. CHORD	9.8	5.7	10.0
LOC. OF L.E.	16.1	46.8	36.0

ENGINE

NUMBER	2.
LENGTH	8.3
DIAM.	4.0
WEIGHT	1425.0
TSLS	9300.
SFCSLS	0.36

WEIGHTS

	W	WG
STRUCT.	13787.	31.1
PROPUL.	3297.	7.4
FIX. EQ.	10009.	22.6
FUEL	15030.	33.9
PAYLOAD	1039.	2.3
OPER IT	1244.	2.8

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
TAKEOFF	0.00	0.	232.	6.0	2597.9				
ACCEL	0.33	0.	27.	0.2	0.9	14.41	13689.1	0.508	161.3
CLIMB	0.44	15000.	297.	3.0	14.1	14.70	8743.0	0.554	161.9
ACCEL	0.59	15000.	65.	0.9	5.2	11.29	7387.4	0.621	291.1
CRUISE	0.59	15000.	4635.	99.8	614.8	10.66	3772.9	0.733	291.1
LOITER	0.34	100.	2497.	60.0	224.8	13.74	2843.9	0.878	170.6
CLIMB	0.44	10000.	157.	1.5	6.8	13.16	10163.9	0.550	197.3
CRUISE	0.59	10000.	5570.	100.1	628.2	7.64	4218.6	0.788	354.7
LOITER	0.34	100.	740.	20.0	74.9	12.35	2497.6	0.889	170.6
LANDING					2797.4				

Block Time = 4.859 hr
Block Range = 1569.8 nm

A-7 JW.IN

```
TRANSPORT
    5    3    5  570  585    0    0    0    0    1    7    0
    0.0001      0.75 800000.00      0.00      0.00      0.00
    1    2    3    4    6
    1    2    6
    1    2    3    4    6
*** Geometry Joined Wing SensorCraft (model 410E)***
$WING
   AR        =     8.166, AREA      =  2755.449, DIHED     =       8.530,
   LFLAPC    =     0.100, SWEEP     =    38.000, TAPER     =     0.610,
   TCROOT    =     0.080, TCTIP     =     0.080, TFLAPC    =     0.234,
   WFFRAC    =     0.800, XWING     =     0.000, ZROOT     =     0.000,
   FDENWG    =     50.00, OUTCOD    =         2, KSWEEP    =         0,
$END
$HTAIL
   AR        =    15.896, AREA      =   727.683, SWEEP     =   -38.000,
   TAPER     =     0.990, TCROOT    =     0.140, TCTIP     =     0.140,
   XHTAIL    =      1.000, ZROOT     =      2.000, KSWEEP    =         0,
   OUTCOD    =         2, SIZIT     =     false,
$END
$VTAIL
   AR        =      0.785, AREA      =    331.419, SWEEP     =     70.223,
   TAPER     =     0.990, TCROOT    =     0.120, TCTIP     =     0.120,
   VTNO      =     1.000, XVTAIL    =     1.000, YROOT     =     0.000,
   ZROOT     =     0.000, KSWEEP    =         1, OUTCOD    =         false,
   SIZIT     =   false,
$END
$FPOD
   DIAM      =     0, LENGTH    =     0.000, X         =    -0.364,
   SOD       =     0.000, THETA     =    28.178, SYMCOD    =         0,
   OUTCOD    =         2,
$END
$FUS
   BDMAX     =     8.820, BODL      =     48.780,  FRAB      =     2.789,
   FRN       =     1.202, WFUEL     =           0.000,  SFFACT    =      1.000,
   ITAIL     =         1, OUTCOD    =         2,
$END
$FUEL
   FRAC      =     0.500, WFUEL     =0.000,  DEN     =        50.00,
   OUTCOD    =         2,
$END
$FUEL
   FRAC      =     0.500, WFUEL     =0.000,  DEN     =        50.00,
   OUTCOD    =         2,
$END
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$TRDATA
   TIMTO1    =    20.000, FWGMAX    =     1.200, TIMTO2    =     0.500,
   QMAX      =    700.000, FRFURE    =     0.050, XDESC     =     80.000,
   DESLF     =     2.000, WKFUEL    =     1.000, CRMACH    =     0.850,
   RANGE     =  3000.000, WKLAND    =     0.570, WFUEL     =   90000.000,
   FLFAC     =     1.000, WFEXT     =     0.000, DECEL     =     0.250,
   WFTRAP    =   100.000, NCRUSE    =         2, IPSTO1    =         5,
   IPSTO2    =         2, IPSIZE    =        -3, IPRINT    =         0,
   KERROR    =         2, MMPROP    =         1,
$END
        8   0.0E+00
         MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME    TURN  'G'S  WKFUEL M IP IX W B A P
------- ---- ----  ----- -----  ------ -----   ---- -----  ------ - -- -- - - - -
CLIMB   0.00 0.00      0 20000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.00 0.00  20000 40000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.00 0.00  40000 55000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CRUISE   .85 0.85  55000 55000  3000.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
LOITER   .80 0.80  55000 55000     0.0 720.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
CLIMB   0.00 0.00     -1 68000     0.0     0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
```

```
CRUISE   .85 0.85  68000 68000  3000.0   0.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
LOITER  0.80 0.80    100   100     0.0  20.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
***** AERODYNAMICS *****
$ACHAR
   XCDW      =     0.600, AMC       =    40.000, SMNDR     =     0.930,
   BTEF      =     0.000, RCLMAX    =     1.000, ROC       =     0.020,
   SFWF      =     0.630, ALELJ     =         2, IDELTA    =         0,
   INORM     =         1, ISMNDR    =         0, ISUPCR    =         0,
   ITRAP     =         1, IXCD      =         1,
   ELLIPC    =     false, ELLIPH    =     false, ELLIPW    =   false,
   SMNSWP    =  0.000, 0.100, 0.200, 0.300, 0.400, 0.500, 0.600, 0.700, 0.800, 0.900,
   CLOW      =   0.430,  0.430,  0.430,  0.430,  0.430,  0.430,  0.430,  0.430,  0.430,
0.430,
   CMO       =      0.000,     0.000,     0.000,     0.000,     0.000,     0.000,
0.000,     0.000,     0.000,     0.000,
$END
$AMULT
   CSF       =     0.000, ESSF      =     0.000, FCD       =     1.000,
   FCDF      =    0.950, FCDL      =     1.000, FCDW      =     1.000,
   FCDWB     =     1.000, FENG      =     1.000, FINTF     =     1.000,
   FLBCOR    =     1.000, FLECOR    =     1.000, FMDR      =     1.000,
$END
$ATRIM
   FVCAM     =       1.000,     1.000,     1.000,     1.000,      1.000,    1.000,
1.000,     1.000,     1.000,     1.000,
   FLDM      =       1.000,     1.000,     1.000,     1.000,      1.000,    1.000,
1.000,     1.000,     1.000,     1.000,
   ITRIM     =       1,     1,     1,     1,      1,     1,     1,     1,     1,     1,
   CFLAP     =     0.200, CGM       =     0.250,  IT        =     0.000,
   SM        =     .100, SPANF     =     0.750,  ZCG       =     0.000,
   IVCAM     =       1,
$END
$ADET
   IPLOT     =         1, NALF      =        10, NMDTL     =         8,
   ICOD      =         1,
   ALIN      =      0.000,      0.500,     1.000,      1.500,      2.000,      4.000,
6.000,      8.000,    10.000,    12.000,
   ALTV      =  50000.000,   50000.000,   50000.000,   65000.000,   65000.000,
65000.000,  65000.000,   55000.000,
   SMN       =    0.600,     0.800,     0.700,    0.600,    0.700,    0.800,   0.850,
0.850,
   ISTRS     =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   ITB       =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
   ITS       =     0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
$END
$ADRAG
   ICDO      =         0,
   CDBMB     =    10*0.0,
   CDEXTR    =    10*0.0,
   CDTNK     =    10*0.0,
$END
$ATAKE
   CLLAND    =        -1, CLTO      =        -1, DELFLD    =     35.000,
   DELFTO    =       25.000, DELLED    =       25.000, DELLTO    =     25.000,
   LDLAND    =        -1, LDTO      =        -1,
$END
$APRINT
   ECHOIN    =         1, ECHOUT    =         0, INTM      =         0,
   IPBLNT    =         0, IPCAN     =         0, IPENG     =         0,
   IPEXT     =         0, IPFLAP    =         0, IPFRIC    =         0,
   IPINTF    =         0, IPLIFT    =         0, IPMIN     =         0,
   IPWAVE    =         0, KERROR    =         0,
$END
*** Propulsion for JW model **Modified** SCALED 5 BPR, 50,000 lbf class (747-like) ***
4
$LEWIS
ESF    =     0.6085, TWOAB  =    30425.000, SFSFC1 = 0.700, BA =  5.000,
ALTD   =        0, 30000, 40000, 50000, 50000, 60000,
XMACH  =        0,   0.6,   0.8,   0.8,   0.6,   0.6,
```

```
$END
$AFTBD
$END
TRANSPORT
***** WEIGHTS *****
$OPTS
   WGTO      =115000.000, AFMACH    =     0.850, IDELT     =         0,
   KBODY     =        2,  KWING     =         1,
   SLOPE     =
0.237,2.110,0.750,0.420,0.315,0.805,0.819,0.819,1.000,0.520,1.000,0.000,1.000,0.000,1.426
,0.458,0.000,1.000,1.000,1.000,
   TECHI     = 1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,
$END
$FIXW
   WBODY  =          0.000,   WHT    =          0.000,   WLG    =          0.000,
   WELT   =          0.000,   WNA    =           0.000,   WVT    =          0.000,
   WWING  =          0.000,   WGEAR  =             0.000,   WPL    =          8862.000,
   WAPU   =           0.000,   WSC    =          0.000,   WEP    =          0.000,
$END
```

A-8 JW.OUT

```
     AAAAAAA   CCCCCCC   SSSSSSS   Y     Y   N     N   TTTTTTT
     A     A   C         S          Y   Y    NN    N      T
     A     A   C         S           Y Y     N N   N      T
     AAAAAAA   C         SSSSSSS      Y      N  N  N      T
     A     A   C               S      Y      N   N N      T
     A     A   C               S      Y      N    N       T
     A     A   CCCCCCC   SSSSSSS      Y      N     N      T


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                         T I T L E
 ________________________________________________________________________________

 AIRCRAFT TYPE - TRANSPORT
1 TITLE: JOINED WING SENSORCRAFT
 ________________________________________________________________________________

 AIRCRAFT TYPE - TRANSPORT

 CONTROL PARAMETERS:
 READ CONTROL,                       MREAD =    5
 EXECUTION CONTROL,                  MEXEC =    3
 WRITE CONTROL,                     MWRITE =    5
 NUMBER IDENTIFYING CONVERGENCE
   VARIABLE FOR CONVERGED VEHICLE,    IOBJ =  570
 NUMBER IDENTIFYING COMPARISON
   VARIABLE FOR CONVERGED VEHICLE,    JOBJ =  585
 SUMMARY OUTPUT PRINT CODE,          IPSUM =    0
 GLOBAL ERROR PRINT CODE,           KGLOBP =    0
 GLOBAL COMMON INITIALIZATION CODE,   INIT =    0
 DEBUG PRINT CODE,                   IPDBG =    0
 GLOBAL PLOT CONTROL,                IGPLT =    1
 DATA TRANSFER INFORMATION FILE, IRDDTR   =    7
 DATA TRANSFER INFORMATION PRINT, IPDTR   =    0

 VEHICLE CONVERGENCE INFORMATION:
 CONVERGENCE TOLERANCE, TOL = 0.10000E-03
 ESTIM WCALC VS WEXT SLOPE  = 0.75000E+00
 BOUNDING WEIGHT, WGMAX     = 0.80000E+06

 MODULE IDENTIFICATION NUMBERS:

  NUMBER      MODULE
     1       GEOMETRY
     2       TRAJECTORY
     3       AERODYNAMICS
     4       PROPULSION
     5       STABILITY AND CONTROL
     6       WEIGHTS
     8       SONIC BOOM
     9       ECONOMICS
    11       SUMMARY OUTPUT
    12       AGILITY
    14       TAKEOFF AND LANDING

 MODULES ARE CALLED FOR INPUT IN THE FOLLOWING ORDER:
     1    2    3    4    6

 MODULES ARE CALLED FOR EXECUTION IN THE FOLLOWING ORDER:
     1    2    6

 MODULES ARE CALLED FOR OUTPUT IN THE FOLLOWING ORDER:
     1    2    3    4    6
```

Fuselage Definition (Type 2)

Nose Length..................	10.602
Nose Fineness Ratio..........	1.202
Constant Section Length......	13.579
Afterbody Length.............	24.599
Afterbody Fineness Ratio.....	2.789
Overall Length...............	48.780
Maximum Diameter.............	8.820
Body Planform Area...........	342.185

Fuselage Definition			Nacelle Definition			Nacelle Location		
X	R	Area	X-Xnose	R	Area	X	Y	Z
0.00	0.00	0.00	0.00	3.33	34.75	-17.76	6.82	3.65
0.53	0.77	1.86	5.93	3.33	34.75	-17.76	-6.82	3.65
1.06	1.27	5.06	17.80	3.33	34.75			
1.59	1.69	8.93	23.74	3.33	34.75			
2.12	2.05	13.20						
2.65	2.37	17.68						
3.18	2.66	22.25						
3.71	2.92	26.81						
4.24	3.16	31.28						
4.77	3.37	35.59						
5.30	3.55	39.68						
5.83	3.72	43.51						
6.36	3.87	47.04						
6.89	4.00	50.22						
7.42	4.11	53.04						
7.95	4.20	55.46						
8.48	4.28	57.47						
9.01	4.34	59.05						
9.54	4.38	60.18						
10.07	4.40	60.87						
10.60	4.41	61.10						
11.96	4.41	61.10						
13.32	4.41	61.10						
14.68	4.41	61.10						
16.03	4.41	61.10						
17.39	4.41	61.10						
18.75	4.41	61.10						
20.11	4.41	61.10						
21.47	4.41	61.10						
22.82	4.41	61.10						
24.18	4.41	61.10						
25.41	4.40	60.87						
26.64	4.38	60.18						
27.87	4.34	59.05						
29.10	4.28	57.47						
30.33	4.20	55.46						
31.56	4.11	53.04						
32.79	4.00	50.22						
34.02	3.87	47.04						
35.25	3.72	43.51						
36.48	3.55	39.68						
37.71	3.37	35.59						
38.94	3.16	31.28						
40.17	2.92	26.81						
41.40	2.66	22.25						
42.63	2.37	17.68						
43.86	2.05	13.20						
45.09	1.69	8.93						
46.32	1.27	5.06						
47.55	0.77	1.86						
48.78	0.00	0.00						

	Fuselage		Nacelles - 2
Max. Diameter......	8.820	.....	6.652
Fineness Ratio.....	5.531		
Surface Area.......	1095.477	.....	496.058 (each)
Volume.............	2096.445		

Dimensions of Planar Surfaces (each)

	Wing	H.Tail	V.Tail	Canard	Units
NUMBER OF SURFACES.	1.0	1.0	1.0	1.0	
PLAN AREA..........	2755.4	727.7	331.4	0.0	(SQ.FT.)
SURFACE AREA.......	5129.3	1469.6	484.4	0.0	(SQ.FT.)
VOLUME.............	2803.4	482.5	572.0	0.0	(CU.FT.)
SPAN...............	150.003	107.551	16.130	0.000	(FT.)
L.E. SWEEP.........	38.000	-38.000	70.244	0.000	(DEG.)
C/4 SWEEP..........	36.929	-38.011	70.223	0.000	(DEG.)
T.E. SWEEP.........	33.530	-38.045	70.160	0.000	(DEG.)
ASPECT RATIO	8.166	15.896	0.785	0.000	
ROOT CHORD.........	22.819	6.800	20.651	0.000	(FT.)
ROOT THICKNESS.....	21.906	11.424	29.737	0.000	(IN.)
ROOT T/C	0.080	0.140	0.120	0.000	
TIP CHORD..........	13.920	6.732	20.444	0.000	(FT.)
TIP THICKNESS......	13.363	11.310	29.439	0.000	(IN.)
TIP T/C	0.080	0.140	0.120	0.000	
TAPER RATIO	0.610	0.990	0.990	0.000	
MEAN AERO CHORD....	18.729	6.766	20.547	0.000	(FT.)
LE ROOT AT.........	-5.705	86.651	28.129	0.000	(FT.)
C/4 ROOT AT........	0.000	88.351	33.292	0.000	(FT.)
TE ROOT AT.........	17.114	93.451	48.780	0.000	(FT.)
LE M.A.C. AT.......	21.228	65.679	50.547	0.000	(FT.)
C/4 M.A.C. AT......	25.911	67.371	55.684	0.000	(FT.)
TE M.A.C. AT.......	39.957	72.445	71.094	0.000	(FT.)
Y M.A.C. AT........	34.473	26.843	0.000	0.000	
LE TIP AT..........	52.893	44.637	73.039	0.000	(FT.)
C/4 TIP AT.........	56.373	46.320	78.150	0.000	(FT.)
TE TIP AT..........	66.813	51.369	93.483	0.000	(FT.)
ELEVATION..........	0.000	16.130	0.000	0.000	(FT.)

GEOMETRIC TOTAL VOLUME COEFF	0.651	0.028	0.000
REQUESTED TOTAL VOLUME COEFF	0.651	0.028	0.000
ACTUAL TOTAL VOLUME COEFF	0.651	0.028	0.000

E X T E N S I O N S

	Strake	Rear Extension
Centroid location at.......	0.00	0.00
Area.......................	0.00	0.00
Sweep Angle................	0.00	0.00
Wetted Area................	0.00	0.00
Volume.....................	0.00	0.00

Total Wing Area............ 2755.45
Total Wetted Area.......... 9170.88
*** ERROR *** FORWARD STRAKE NOT POSITIONED CORRECTLY

F U E L T A N K S

Tank	Volume	Weight	Density
Wing	1177.	58829.	50.00
Fus#1	32.	1587.	50.00
Fus#2	32.	1587.	50.00
Total		62003.	

Mission Fuel Required = 62003. lbs.
Extra Fuel Carrying Capability = -3174. lbs.
Available Fuel Volume in Wing = 1177. cu.ft.

Aircraft Weight = 112372.648 lbs.
Aircraft Volume = 5954.385 cu.ft.
Aircraft Density = 18.872 lbs./cu.ft.
Actual - Required Fuel Volume = -63.481 cu.ft.

ICASE = 4 (Fineness Ratio Method)

Trajectory Output

Mission 1 (PAYLOAD = 8862. LB)

PHASE	M	H	CL	ALPHA	WFUEL	TIME	VEL
	SFC(I)	THRUST(I)	CD	GAMMA	W	WA	Q
	SFC(U)	THRUST(U)	CDINST	L/D	THR/THA	PR	X
WARM-UP		0.			721.2	20.00	
	9.90	218.					
TAKEOFF	0.11	0.	2.3796	13.71	134.1	0.50	119.
	0.28	57848.	0.3552	21.72	111651.4	959.35	17.
	0.28	57848.	0.0020	6.70	1.00	1.00	1666.
2ND SEG	0.11	400.	2.3796	13.71			119.
	0.28	28924.	0.3552	6.38	111651.4	959.35	17.
	0.28	57848.	0.0020	6.70	1.00	1.00	
CLIMB	0.49	20000.	0.1656	-5.05	691.4	3.18	508.
	0.40	25319.	0.0151	9.56	110825.9	543.40	164.
Cycle	0.39	25574.	0.0006	10.97	1.00	1.00	15.
CLIMB	0.66	40000.	0.2629	-3.69	768.8	6.40	643.
	0.45	11746.	0.0147	3.54	110057.1	263.38	122.
Cycle	0.44	11836.	0.0003	17.89	1.00	1.00	36.
CLIMB	0.82	55000.	0.3901	-2.10	776.4	12.25	796.
	0.48	5872.	0.0167	0.88	109280.7	145.80	91.
Cycle	0.47	5972.	0.0004	23.31	1.00	1.00	90.
CRUISE	0.85	55000.	0.3653	-2.50	14690.3	351.85	823.
	0.47	4750.	0.0208	0.00	94590.4	138.37	97.
Cycle	0.45	4937.	0.0007	17.58	0.81	1.00	2859.
LOITER	0.80	55000.	0.3995	-2.01	21644.9	720.00	774.
	0.45	4036.	0.0170	0.00	72945.5	129.68	86.
Cycle	0.43	4185.	0.0006	23.45	0.69	1.00	5506.
CLIMB	0.79	65600.	0.4811	-1.12	917.8	35.67	767.
	0.45	2789.	0.0203	-0.05	72027.7	79.32	51.
Cycle	0.43	2872.	0.0006	23.65	0.79	1.00	274.
CRUISE	0.85	68000.	0.4369	-1.57	11012.0	436.00	824.
	0.47	2554.	0.0214	0.00	61015.7	74.25	52.
Cycle	0.45	2654.	0.0007	20.46	0.81	1.00	3548.
LOITER	0.80	100.	0.0234	-6.21	7598.4	20.00	893.
	0.51	45088.	0.0173	0.00	53417.4	1261.36	945.
Cycle	0.49	41352.	0.0005	1.35	1.13	1.00	176.
LANDING	0.12	0.	2.0356	7.32			131.
	0.28	57289.	0.2998	28.10	85754.3	960.73	20.
	0.28	57394.	0.0019	6.79	1.00	1.00	1571.

```
Fuel Summary

 Total Fuel     =  62003.     Takeoff Fuel:         Fuel Load:
   Mission Fuel =  58955.         Warmup  =    721.     External =      0.
   Reserve Fuel =   2948.         Takeoff =    134.     Internal =  62003.
   Trapped Fuel =    100.

 Block Time                        =   26.764 hrs
 Block Range                       =  12504.8 n.m.
 Block Fuel                        =  58955.3 lb.

 Takeoff Field Length (total run)  =    1666. ft
 Landing Field Length (total run)  =    1571. ft   Decel @ .250 Gs
 Landing Field Length (ground run) =     837. ft   Field Length Factor = 1.000
 Weight for Landing calculation    =   85754. lbs
 Landing Thrust to Weight ratio    =    0.668
 Takeoff Weight                    =  112373. lbs
 Landing Weight                    =   53417. lbs
```

```
Mach      =    0.25  C.G. Location =  25.9 ft, 0.25 cbar
 Altitude =      0.  Takeoff Configuration:  Flaps and Slats

 Parasite Drag       Induced Drag
 Friction      .0072   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
  Body         .0010    -0.3 1.163 0.0904 12.9 0.58  2  0.000 -.0025     1.3 0.340
  Wing         .0037     0.3 1.217 0.0988 12.3 0.58  2  0.000 -.0019     0.9 0.341
  Strakes      .0000     0.9 1.271 0.1074 11.8 0.58  2  0.000 -.0012     0.6 0.342
  H. Tail      .0020     1.4 1.324 0.1162 11.4 0.59  2  0.000 -.0005     0.2 0.342
  V. Tail      .0005     2.0 1.377 0.1252 11.0 0.59  2  0.000 0.0003    -0.1 0.343
  Canard       .0000     4.4 1.587 0.1628  9.8 0.60  2  0.000 0.0039    -1.6 0.346
                         6.7 1.794 0.2029  8.8 0.62  2  0.000 0.0082    -3.2 0.349
                         9.1 1.998 0.2501  8.0 0.62  2  0.000 0.0131    -4.7 0.352
                        11.4 2.200 0.3024  7.3 0.62  2  0.000 0.0185    -6.4 0.355
                        13.8 2.399 0.3599  6.7 0.62  2  0.000 0.0246    -8.1 0.358
 Interference  .0014
 Wave          .0000
 External      .0000                     Slope Factors
  Tanks        .0000                       Cl/Alpha (per radian)        5.0318
  Bombs        .0000                       Cdl/Cl^2                     0.0626
  Stores       .0000                     Alpha Transition Zone 2-3     16.189
  Extra        .0000
 Camber        .0090                     Flap Setting                     25.
 ___________________                     Slat Setting                     25.
 Cdmin         .0175                     Flap Type        Single         388. sq. ft

 Mach     =    0.25  C.G. Location =  25.9 ft, 0.25 cbar
 Altitude =      0.  Landing Configuration:  Flaps and Slats

 Parasite Drag       Induced Drag
 Friction      .0072   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
  Body         .0010    -0.4 1.372 0.1419  9.7 0.52  2  0.000 -.0040     1.7 0.341
  Wing         .0037     0.2 1.424 0.1529  9.3 0.52  2  0.000 -.0034     1.4 0.342
  Strakes      .0000     0.8 1.476 0.1641  9.0 0.52  2  0.000 -.0027     1.1 0.343
  H. Tail      .0020     1.3 1.527 0.1755  8.7 0.52  2  0.000 -.0019     0.8 0.344
  V. Tail      .0005     1.9 1.578 0.1871  8.4 0.52  2  0.000 -.0011     0.4 0.344
  Canard       .0000     4.2 1.782 0.2349  7.6 0.53  2  0.000 0.0027    -1.0 0.348
                         6.5 1.982 0.2849  7.0 0.54  2  0.000 0.0072    -2.5 0.351
                         8.9 2.179 0.3389  6.4 0.55  2  0.000 0.0124    -4.0 0.355
                        11.2 2.375 0.3996  5.9 0.55  2  0.000 0.0180    -5.6 0.359
                        13.6 2.568 0.4651  5.5 0.55  2  0.000 0.0243    -7.2 0.363
 Interference  .0014
 Wave          .0000
 External      .0000                     Slope Factors
  Tanks        .0000                       Cl/Alpha (per radian)        4.9035
  Bombs        .0000                       Cdl/Cl^2                     0.0706
  Stores       .0000                     Alpha Transition Zone 2-3     16.189
  Extra        .0000
 Camber        .0090                     Flap Setting                     35.
 ___________________                     Slat Setting                     25.
 Cdmin         .0175                     Flap Type        Single         388. sq. ft
```

```
Detailed Aerodynamics Output

Mach     =    0.60  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  50000.  Reynolds Number per foot =  711688.

Parasite Drag       Induced Drag
Friction      .0071   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0010    -0.3 0.557 0.0231 24.1 0.51  2  0.000 -.0012     1.3 0.344
 Wing         .0037     0.3 0.607 0.0260 23.3 0.54  2  0.000 -.0008     0.8 0.344
 Strakes      .0000     0.9 0.656 0.0289 22.7 0.57  2  0.000 -.0003     0.3 0.344
 H. Tail      .0020     1.5 0.705 0.0320 22.0 0.60  2  0.000 0.0002    -0.2 0.344
 V. Tail      .0005     2.1 0.754 0.0354 21.3 0.62  2  0.000 0.0008    -0.6 0.345
 Canard       .0000     4.6 0.956 0.0535 17.9 0.66  2  0.000 0.0037    -2.6 0.379
                        7.1 1.185 0.0798 14.9 0.68  3  0.000 0.0012    -4.6 0.386
                        9.6 1.337 0.1168 11.4 0.59  3  0.000 0.0042    -6.5 0.397
                       12.1 1.479 0.1645  9.0 0.52  3  0.000 0.0093    -8.5 0.413
                       14.8 1.610 0.2236  7.2 0.45  3  0.000 0.0172   -10.6 0.434
Interference  .0014
Wave          .0000
External      .0000                     Slope Factors
 Tanks        .0000                       Cl/Alpha (per radian)        4.0113
 Bombs        .0000                       Cdl/Cl^2                     0.0864
 Stores       .0000                     Alpha Transition Zone 2-3      4.367
 Extra        .0000
Camber        .0090                     Programmed Flap Setting           0.
___________________
Cdmin         .0175                     Flap Type        Single         388. sq. ft

Mach     =    0.80  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  50000.  Reynolds Number per foot =  948917.

Parasite Drag       Induced Drag
Friction      .0067   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0010    -0.2 0.564 0.0231 24.4 0.52  2  0.000 -.0011     1.2 0.340
 Wing         .0034     0.4 0.618 0.0262 23.6 0.55  2  0.000 -.0007     0.7 0.340
 Strakes      .0000     1.0 0.671 0.0295 22.8 0.58  2  0.000 -.0002     0.2 0.340
 H. Tail      .0019     1.6 0.725 0.0328 22.1 0.61  2  0.000 0.0004    -0.3 0.340
 V. Tail      .0005     2.2 0.817 0.0373 21.9 0.68  2  0.000 0.0012    -1.0 0.386
 Canard       .0000     4.7 1.040 0.0557 18.7 0.75  3  0.000 0.0005    -3.1 0.389
                        7.2 1.205 0.0854 14.1 0.66  3  0.000 0.0027    -5.1 0.396
                        9.7 1.360 0.1262 10.8 0.57  3  0.000 0.0070    -7.2 0.407
                       12.3 1.505 0.1785  8.4 0.49  3  0.000 0.0139    -9.3 0.423
                       15.0 1.640 0.2428  6.8 0.43  3  0.000 0.0240   -11.5 0.444
Interference  .0014
Wave          .0000
External      .0000                     Slope Factors
 Tanks        .0000                       Cl/Alpha (per radian)        4.0605
 Bombs        .0000                       Cdl/Cl^2                     0.0906
 Stores       .0000                     Alpha Transition Zone 2-3      2.061
 Extra        .0000
Camber        .0090                     Programmed Flap Setting           0.
___________________
Cdmin         .0171                     Flap Type        Single         388. sq. ft
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Detailed Aerodynamics Output

Mach     =    0.70  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  50000.  Reynolds Number per foot =  830302.

Parasite Drag       Induced Drag
Friction      .0069   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0010    -0.2 0.560 0.0230 24.3 0.52  2  0.000 -.0012     1.2 0.343
 Wing         .0035     0.4 0.611 0.0260 23.5 0.55  2  0.000 -.0007     0.7 0.343
 Strakes      .0000     1.0 0.663 0.0291 22.8 0.57  2  0.000 -.0003     0.2 0.343
 H. Tail      .0019     1.5 0.713 0.0323 22.1 0.60  2  0.000 0.0003    -0.2 0.343
 V. Tail      .0005     2.1 0.764 0.0359 21.3 0.62  2  0.000 0.0009    -0.7 0.344
 Canard       .0000     4.7 1.032 0.0542 19.0 0.76  3  0.000 0.0001    -2.9 0.384
                        7.1 1.194 0.0824 14.5 0.67  3  0.000 0.0019    -4.9 0.392
                        9.7 1.347 0.1211 11.1 0.58  3  0.000 0.0055    -6.9 0.403
                       12.2 1.491 0.1711  8.7 0.50  3  0.000 0.0115    -8.9 0.418
                       14.9 1.624 0.2326  7.0 0.44  3  0.000 0.0204   -11.0 0.439
Interference  .0014
Wave          .0000
External      .0000                     Slope Factors
 Tanks        .0000                       Cl/Alpha (per radian)        4.0324
 Bombs        .0000                       Cdl/Cl^2                     0.0885
 Stores       .0000                     Alpha Transition Zone 2-3      3.072
 Extra        .0000
Camber        .0090                     Programmed Flap Setting           0.
___________________
Cdmin         .0173                     Flap Type        Single         388. sq. ft

Mach     =    0.60  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  65000.  Reynolds Number per foot =  347459.

Parasite Drag       Induced Drag
Friction      .0081   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0011    -0.3 0.557 0.0241 23.1 0.51  2  0.000 -.0012     1.3 0.344
 Wing         .0042     0.3 0.607 0.0270 22.5 0.54  2  0.000 -.0008     0.8 0.344
 Strakes      .0000     0.9 0.656 0.0299 21.9 0.57  2  0.000 -.0003     0.3 0.344
 H. Tail      .0023     1.5 0.705 0.0329 21.4 0.60  2  0.000 0.0002    -0.2 0.344
 V. Tail      .0005     2.1 0.754 0.0364 20.7 0.62  2  0.000 0.0008    -0.6 0.345
 Canard       .0000     4.6 0.956 0.0545 17.6 0.66  2  0.000 0.0037    -2.6 0.379
                        7.1 1.185 0.0807 14.7 0.68  3  0.000 0.0012    -4.6 0.386
                        9.6 1.337 0.1177 11.4 0.59  3  0.000 0.0042    -6.5 0.397
                       12.1 1.479 0.1655  8.9 0.52  3  0.000 0.0094    -8.5 0.413
                       14.8 1.610 0.2246  7.2 0.45  3  0.000 0.0173   -10.6 0.434
Interference  .0014
Wave          .0000
External      .0000                     Slope Factors
 Tanks        .0000                       Cl/Alpha (per radian)        4.0114
 Bombs        .0000                       Cdl/Cl^2                     0.0864
 Stores       .0000                     Alpha Transition Zone 2-3      4.367
 Extra        .0000
Camber        .0090                     Programmed Flap Setting           0.
___________________
Cdmin         .0185                     Flap Type        Single         388. sq. ft
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Detailed Aerodynamics Output

Mach     =    0.70  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  65000.  Reynolds Number per foot =  405369.

Parasite Drag       Induced Drag
Friction      .0078   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0011    -0.2 0.560 0.0240 23.4 0.52  2  0.000 -.0012     1.2 0.343
 Wing         .0040     0.4 0.611 0.0269 22.7 0.55  2  0.000 -.0007     0.7 0.343
 Strakes      .0000     1.0 0.663 0.0300 22.1 0.57  2  0.000 -.0003     0.2 0.343
 H. Tail      .0022     1.5 0.713 0.0332 21.5 0.60  2  0.000 0.0003    -0.2 0.343
 V. Tail      .0005     2.1 0.764 0.0368 20.8 0.62  2  0.000 0.0009    -0.7 0.344
 Canard       .0000     4.7 1.032 0.0551 18.7 0.76  3  0.000 0.0001    -2.9 0.384
                        7.1 1.194 0.0833 14.3 0.67  3  0.000 0.0019    -4.9 0.392
                        9.7 1.348 0.1221 11.0 0.58  3  0.000 0.0055    -6.9 0.403
                       12.2 1.491 0.1720  8.7 0.50  3  0.000 0.0115    -8.9 0.418
                       14.9 1.624 0.2336  7.0 0.44  3  0.000 0.0204   -11.0 0.439
Interference  .0014
Wave          .0000
External      .0000                     Slope Factors
 Tanks        .0000                       Cl/Alpha (per radian)        4.0322
 Bombs        .0000                       Cdl/Cl^2                     0.0885
 Stores       .0000                     Alpha Transition Zone 2-3      3.072
 Extra        .0000
Camber        .0090                     Programmed Flap Setting           0.
___________________
Cdmin         .0182                     Flap Type        Single         388. sq. ft

Mach     =    0.80  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  65000.  Reynolds Number per foot =  463278.

Parasite Drag       Induced Drag
Friction      .0075   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0011    -0.2 0.564 0.0239 23.6 0.52  2  0.000 -.0011     1.2 0.340
 Wing         .0039     0.4 0.618 0.0270 22.9 0.55  2  0.000 -.0007     0.7 0.340
 Strakes      .0000     1.0 0.671 0.0303 22.2 0.58  2  0.000 -.0002     0.2 0.340
 H. Tail      .0021     1.6 0.725 0.0337 21.5 0.61  2  0.000 0.0004    -0.3 0.340
 V. Tail      .0005     2.2 0.817 0.0381 21.4 0.68  2  0.000 0.0012    -1.0 0.386
 Canard       .0000     4.7 1.040 0.0566 18.4 0.75  3  0.000 0.0005    -3.1 0.389
                        7.2 1.205 0.0862 14.0 0.66  3  0.000 0.0027    -5.1 0.396
                        9.7 1.360 0.1270 10.7 0.57  3  0.000 0.0070    -7.2 0.407
                       12.3 1.505 0.1793  8.4 0.49  3  0.000 0.0139    -9.3 0.423
                       15.0 1.640 0.2437  6.7 0.43  3  0.000 0.0240   -11.5 0.444
Interference  .0014
Wave          .0000
External      .0000                     Slope Factors
 Tanks        .0000                       Cl/Alpha (per radian)        4.0602
 Bombs        .0000                       Cdl/Cl^2                     0.0906
 Stores       .0000                     Alpha Transition Zone 2-3      2.061
 Extra        .0000
Camber        .0090                     Programmed Flap Setting           0.
___________________
Cdmin         .0179                     Flap Type        Single         388. sq. ft
```

Detailed Aerodynamics Output

```
Mach     =    0.85  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  65000.  Reynolds Number per foot =  492233.

Parasite Drag       Induced Drag
Friction      .0074   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0010    -0.2 0.566 0.0264 21.4 0.52  2  0.000 -.0011     1.2 0.337
 Wing         .0038     0.4 0.621 0.0296 21.0 0.55  2  0.000 -.0007     0.7 0.337
 Strakes      .0000     1.0 0.676 0.0330 20.5 0.58  2  0.000 -.0001     0.1 0.337
 H. Tail      .0021     1.6 0.767 0.0370 20.7 0.66  2  0.000 0.0006    -0.5 0.387
 V. Tail      .0005     2.2 0.860 0.0400 21.5 0.77  3  0.000 -.0001    -1.1 0.388
 Canard       .0000     4.7 1.045 0.0599 17.4 0.74  3  0.000 0.0006    -3.2 0.392
                        7.2 1.211 0.0904 13.4 0.65  3  0.000 0.0032    -5.3 0.399
                        9.7 1.367 0.1322 10.3 0.56  3  0.000 0.0079    -7.4 0.410
                       12.3 1.513 0.1858  8.1 0.49  3  0.000 0.0153    -9.5 0.425
                       15.0 1.649 0.2517  6.6 0.43  3  0.000 0.0260   -11.7 0.446
Interference  .0012
Wave          .0028
External      .0000                       Slope Factors
 Tanks        .0000                         Cl/Alpha (per radian)        4.0770
 Bombs        .0000                         Cdl/Cl^2                     0.0917
 Stores       .0000                       Alpha Transition Zone 2-3      1.629
 Extra        .0000
Camber        .0090                       Programmed Flap Setting           0.
___________________
Cdmin         .0203                       Flap Type        Single         388. sq. ft

Mach     =    0.85  C.G. Location =  25.9 ft, 0.25 cbar
Altitude =  55000.  Reynolds Number per foot =  793802.

Parasite Drag       Induced Drag
Friction      .0068   Alpha    Cl     Cd  L/D    e Zone  Cm  Cdtrim Deltrim StMrg
 Body         .0010    -0.2 0.566 0.0258 21.9 0.52  2  0.000 -.0011     1.2 0.337
 Wing         .0035     0.4 0.621 0.0290 21.4 0.55  2  0.000 -.0007     0.7 0.337
 Strakes      .0000     1.0 0.676 0.0324 20.9 0.58  2  0.000 -.0001     0.1 0.337
 H. Tail      .0019     1.6 0.767 0.0364 21.1 0.66  2  0.000 0.0006    -0.5 0.387
 V. Tail      .0005     2.2 0.860 0.0394 21.8 0.77  3  0.000 -.0001    -1.1 0.388
 Canard       .0000     4.7 1.045 0.0593 17.6 0.74  3  0.000 0.0006    -3.2 0.392
                        7.2 1.210 0.0898 13.5 0.65  3  0.000 0.0032    -5.3 0.399
                        9.7 1.367 0.1316 10.4 0.56  3  0.000 0.0079    -7.4 0.410
                       12.3 1.513 0.1852  8.2 0.49  3  0.000 0.0153    -9.5 0.425
                       15.0 1.649 0.2511  6.6 0.43  3  0.000 0.0260   -11.7 0.446
Interference  .0012
Wave          .0028
External      .0000                       Slope Factors
 Tanks        .0000                         Cl/Alpha (per radian)        4.0771
 Bombs        .0000                         Cdl/Cl^2                     0.0917
 Stores       .0000                       Alpha Transition Zone 2-3      1.629
 Extra        .0000
Camber        .0090                       Programmed Flap Setting           0.
___________________
Cdmin         .0198                       Flap Type        Single         388. sq. ft
```

1 ENGINE SUMMARY

ENGINE DIAMETER = 5.78 FEET
ENGINE LENGTH = 11.87 FEET
ENGINE WEIGHT = 5624.82 POUNDS
BYPASS RATIO = 5.00
NO OF ENGINES = 2.
DRAG REF AREA = 2755.45 SQ FEET
PWCC = PERCENT OF ENGINE CORRECTED AIRFLOW
THRUST = ENGINE THRUST (POUNDS PER ENGINE)
SFC = ENGINE SPECIFIC FUEL CONSUMPTION
THRUSTU= THRUST PER ENGINE IN LBS, W/O INSTAL DRAG CORR
SFCU = SFC,1/HR, W/O INSTALLATION DRAG CORR
CDINS = TOT INSTALLATION DRAG COEF PER A/C (SWING REF)

1

MACH	ALT	PWCC	THRUST	THRUSTU	SFC	SFCU	CDINS
0.000	0.	100.	30425.	30425.	0.261	0.261	0.0001
		98.	28820.	28820.	0.261	0.261	0.0001
		96.	26101.	26101.	0.249	0.249	0.0001
		94.	23390.	23390.	0.238	0.238	0.0001
		92.	20659.	20659.	0.229	0.229	0.0001
		90.	17839.	17839.	0.222	0.222	0.0001
		88.	14751.	14751.	0.222	0.222	0.0002
		86.	10712.	10712.	0.249	0.249	0.0002
		84.	4883.	4883.	0.435	0.435	0.0002
		82.	3524.	3524.	0.465	0.465	0.0001
		80.	1683.	1683.	0.719	0.719	0.0000
0.600	30000.	100.	7171.	7290.	0.401	0.395	0.0005
		98.	6327.	6446.	0.396	0.388	0.0005
		96.	5506.	5625.	0.393	0.384	0.0005
		94.	4710.	4828.	0.393	0.383	0.0005
		92.	3936.	4052.	0.399	0.387	0.0005
		90.	3185.	3300.	0.413	0.398	0.0005
		88.	2446.	2558.	0.444	0.425	0.0005
		86.	1696.	1807.	0.520	0.488	0.0005
		84.	1100.	1210.	0.635	0.578	0.0005
		82.	679.	785.	0.791	0.684	0.0005
		80.	211.	305.	1.862	1.291	0.0004
0.800	40000.	100.	4759.	4906.	0.450	0.437	0.0006
		98.	4167.	4321.	0.447	0.431	0.0006
		96.	3601.	3756.	0.447	0.428	0.0006
		94.	3055.	3212.	0.451	0.429	0.0006
		92.	2530.	2688.	0.462	0.434	0.0007
		90.	2026.	2187.	0.483	0.447	0.0007
		88.	1539.	1704.	0.525	0.474	0.0007
		86.	1062.	1232.	0.618	0.532	0.0007
		84.	683.	854.	0.762	0.609	0.0007
		82.	401.	565.	0.997	0.708	0.0007
		80.	109.	256.	2.680	1.143	0.0006
0.800	50000.	100.	2949.	3040.	0.450	0.437	0.0006
		98.	2582.	2678.	0.447	0.431	0.0006
		96.	2231.	2327.	0.447	0.428	0.0006
		94.	1893.	1990.	0.451	0.429	0.0006
		92.	1568.	1666.	0.462	0.434	0.0007
		90.	1255.	1355.	0.483	0.447	0.0007
		88.	954.	1056.	0.525	0.474	0.0007
		86.	658.	764.	0.618	0.532	0.0007

		84.	423.	529.	0.762	0.609	0.0007
		82.	248.	350.	0.997	0.708	0.0007
		80.	68.	159.	2.680	1.143	0.0006
0.600	50000.	100.	2756.	2802.	0.387	0.381	0.0005
		98.	2430.	2476.	0.382	0.375	0.0005
		96.	2113.	2159.	0.379	0.371	0.0005
		94.	1805.	1851.	0.380	0.370	0.0005
		92.	1508.	1553.	0.385	0.374	0.0005
		90.	1219.	1263.	0.399	0.385	0.0005
		88.	935.	978.	0.430	0.411	0.0005
		86.	646.	689.	0.505	0.473	0.0005
		84.	417.	459.	0.620	0.563	0.0005
		82.	253.	294.	0.783	0.675	0.0005
		80.	71.	107.	2.046	1.361	0.0004
0.600	60000.	100.	1708.	1737.	0.387	0.381	0.0005
		98.	1506.	1535.	0.382	0.375	0.0005
		96.	1310.	1339.	0.379	0.371	0.0005
		94.	1119.	1148.	0.380	0.370	0.0005
		92.	935.	963.	0.385	0.374	0.0005
		90.	756.	783.	0.399	0.385	0.0005
		88.	579.	606.	0.430	0.411	0.0005
		86.	401.	427.	0.505	0.473	0.0005
		84.	258.	285.	0.620	0.563	0.0005
		82.	157.	182.	0.783	0.675	0.0005
		80.	44.	66.	2.046	1.361	0.0004

SEA-LEVEL STATIC THRUST = 30425. (MAX)
SEA-LEVEL SFC = 0.261

Weight Statement - Transport

***** WEIGHTS *****

Qmax: 700.
Design Load Factor: 2.00
Ultimate Load Factor: 3.75
Structure and Material: Aluminum Skin, Stringer
Wing Equation: Sanders Equation
Body Equation: Air Force Equation

Component		Pounds	Kilograms	Percent	Slope	Tech	Fixed
Airframe Structure		24161.	10959.	21.50			No
Wing		7643.	3467.	6.80	0.24	1.00	No
Fuselage		6443.	2923.	5.73	2.11	1.00	No
Horizontal Tail	(Low)	4120.	1869.	3.67	0.75	1.00	No
Vertical Tail		1238.	561.	1.10	0.42	1.00	No
Nacelles		864.	392.	0.77	0.31	1.00	No
Landing Gear		3853.	1748.	3.43	0.81	1.00	No
Propulsion		11977.	5433.	10.66			No
Engines	(2)	11056.	5015.	9.84	0.82	1.00	No
Fuel System		921.	418.	0.82	0.82	1.00	No
Fixed Equipment		5265.	2388.	4.69		1.00	No
Hyd & Pneumatic		674.	306.	0.60	1.00		No
Electrical		1066.	483.	0.95	0.52		No
Avionics		1460.	662.	1.30	1.00		No
Instrumentation		0.	0.	0.00	0.00		No
De-ice & Air Cond		0.	0.	0.00	1.00		No
Aux Power System		868.	394.	0.77	1.43		No
Furnish & Eqpt		0.	0.	0.00	0.00		No
Seats and Lavatories		0.	0.	0.00	0.00		No
Galley		0.	0.	0.00	0.00		No
Misc Cockpit		0.	0.	0.00	0.00		No
Cabin Finishing		0.	0.	0.00	0.00		No
Cabin Emergency Equip		0.	0.	0.00	0.00		No
Cargo Handling		0.	0.	0.00	0.00		No
Flight Controls		1198.	544.	1.07	0.46		No
Empty Weight		41404.	18781.	36.85			
Operating Items		200.	91.	0.18			No
Flight Crew	(0)	0.	0.	0.00			No
Crew Baggage and Provisions		100.	45.	0.09			No
Flight Attendents	(0)	0.	0.	0.00			No
Unusable Fuel and Oil		100.	45.	0.09			No
Passenger Service		0.	0.	0.00			No
Cargo Containers		0.	0.	0.00			No
Operating Weight Empty		41604.	18871.	37.02			
Fuel		61903.	28079.	55.09			
Payload		8862.	4020.	7.89			Yes
Passengers	(0)	0.	0.	0.00			No
Baggage		0.	0.	0.00			No
Cargo		0.	0.	0.00			No
		--------	--------	------			
Calculated Weight		112369.	50971.	92.11			No
Estimated Weight		112373.	50972.				
Percent Error				0.00			

Calculated Weight does not equal 100% because a group weight is being fixed.

SUMMARY --- ACSYNT OUTPUT:

GENERAL	
WG	112369.
W/S	40.8
T/W	0.54
N(Z) ULT	3.8
CREW	0.
PASENGERS	0.

FUSELAGE	
LENGTH	48.8
DIAMETER	8.8
VOLUME	2096.4
WETTED AREA	1095.5
FINENESS RATIO	5.5

	WING	HTAIL	VTAIL
AREA	2755.4	727.7	331.4
WETTED AREA	5129.3	1469.6	484.4
SPAN	150.0	107.6	16.1
L.E. SWEEP	38.0	-38.0	70.2
C/4 SWEEP	36.9	-38.0	70.2
ASPECT RATIO	8.17	15.90	0.79
TAPER RATIO	0.61	0.99	0.99
T/C ROOT	0.08	0.14	0.12
T/C TIP	0.08	0.14	0.12
ROOT CHORD	22.8	6.8	20.7
TIP CHORD	13.9	6.7	20.4
M.A. CHORD	18.7	6.8	20.5
LOC. OF L.E.	-5.7	86.7	28.1

ENGINE	
NUMBER	2.
LENGTH	11.9
DIAM.	5.8
WEIGHT	5624.8
TSLS	30425.
SFCSLS	0.26

WEIGHTS	W	WG
STRUCT.	24161.	21.5
PROPUL.	11977.	10.7
FIX. EQ.	5265.	4.7
FUEL	62003.	55.2
PAYLOAD	8862.	7.9
OPER IT	200.	0.2

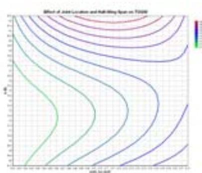
MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
TAKEOFF	0.00	0.	855.	20.5	1666.0				
CLIMB	0.49	20000.	691.	3.2	14.5	10.97	25319.0	0.396	163.6
CLIMB	0.66	40000.	769.	6.4	36.3	17.89	11745.8	0.445	121.5
CLIMB	0.82	55000.	776.	12.3	90.2	23.31	5871.7	0.479	90.7
CRUISE	0.85	55000.	14690.	351.9	2859.0	17.58	4750.0	0.468	97.0
LOITER	0.80	55000.	21645.	720.0	5506.3	23.45	4035.6	0.447	85.9
CLIMB	0.79	65600.	918.	35.7	274.1	23.65	2788.7	0.448	50.8
CRUISE	0.85	68000.	11012.	436.0	3548.1	20.46	2553.8	0.469	52.1
LOITER	0.80	100.	7598.	20.0	176.3	1.35	45088.4	0.506	944.6
LANDING					1571.0				

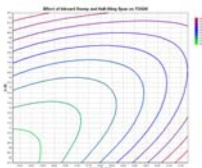
Block Time = 26.764 hr
Block Range =12504.8 nm

Appendix B: Variable Interaction Plots

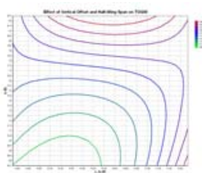
B-1
b vs. j_{loc}



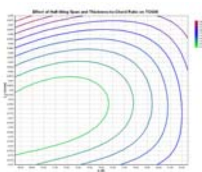
B-2
b vs. Λ_{ib}



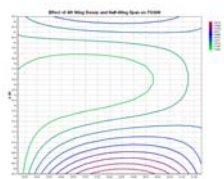
B-3
b vs. z_{fa}
Λ_{ia}



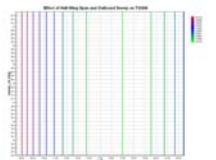
B-4
b vs $^{t}/_{c}$



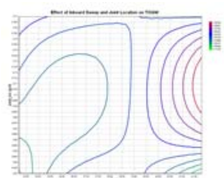
B-5
b vs. Λ_{ia}



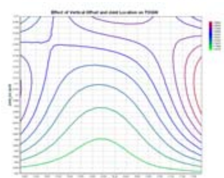
B-6
b vs.Λ_{ob}



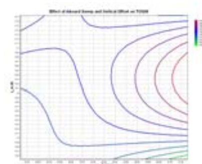
B-7
j_{loc} vs. Λ_{ib}



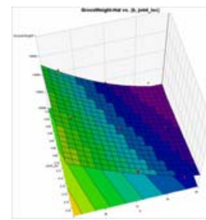
B-8
j_{loc} vs. z_{fa}



B-9
z_{fa} vs. Λ_{ib}

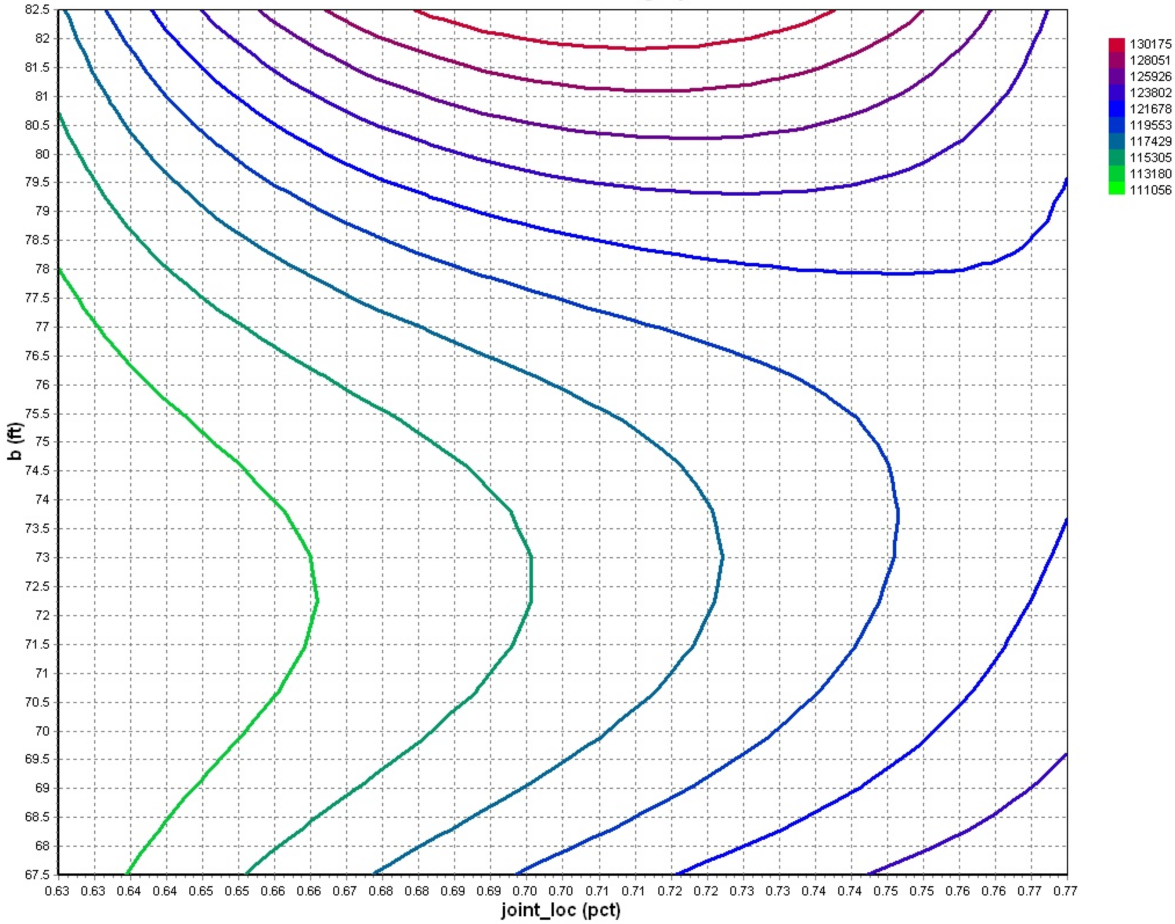


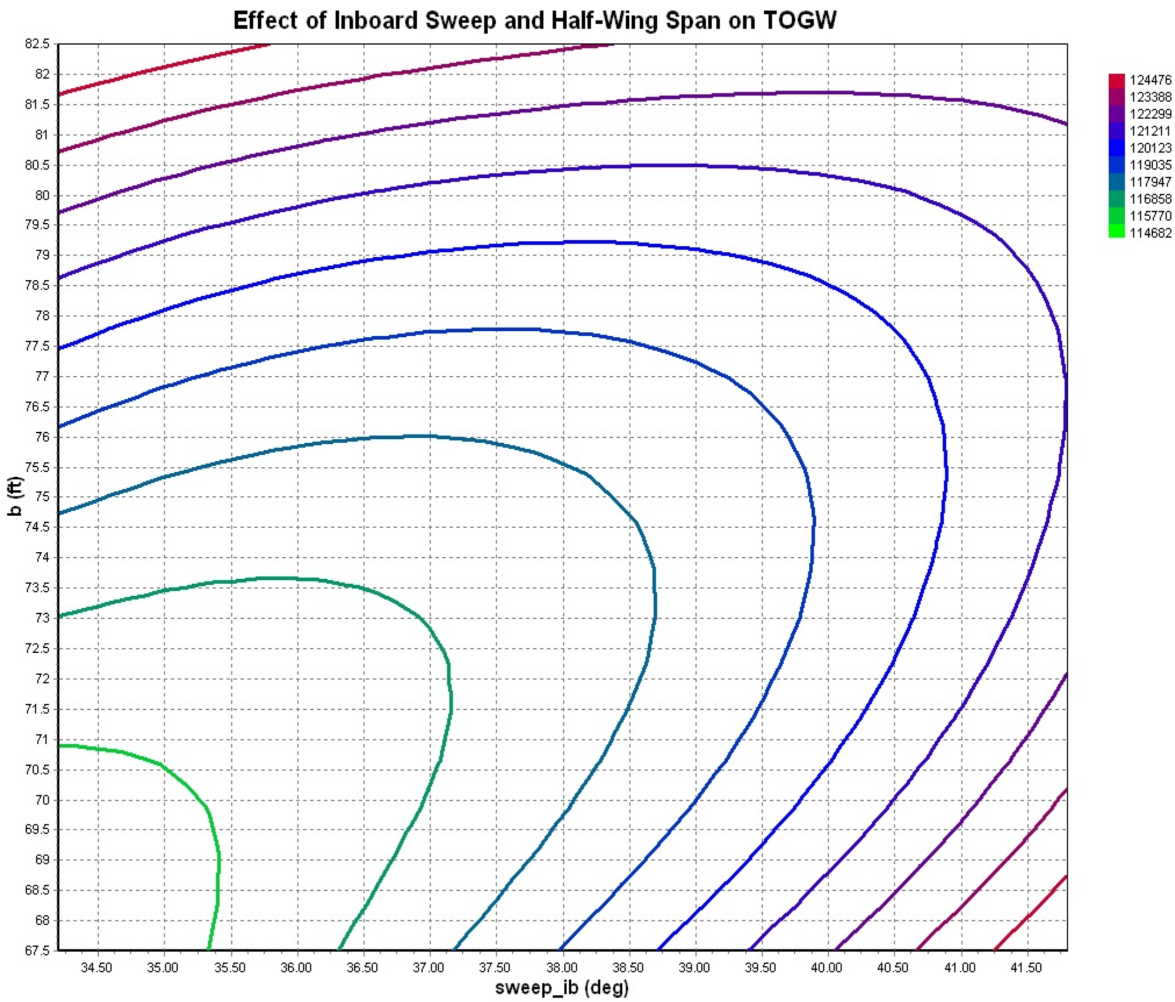
B-10
b vs. j_{loc}
Response Surface



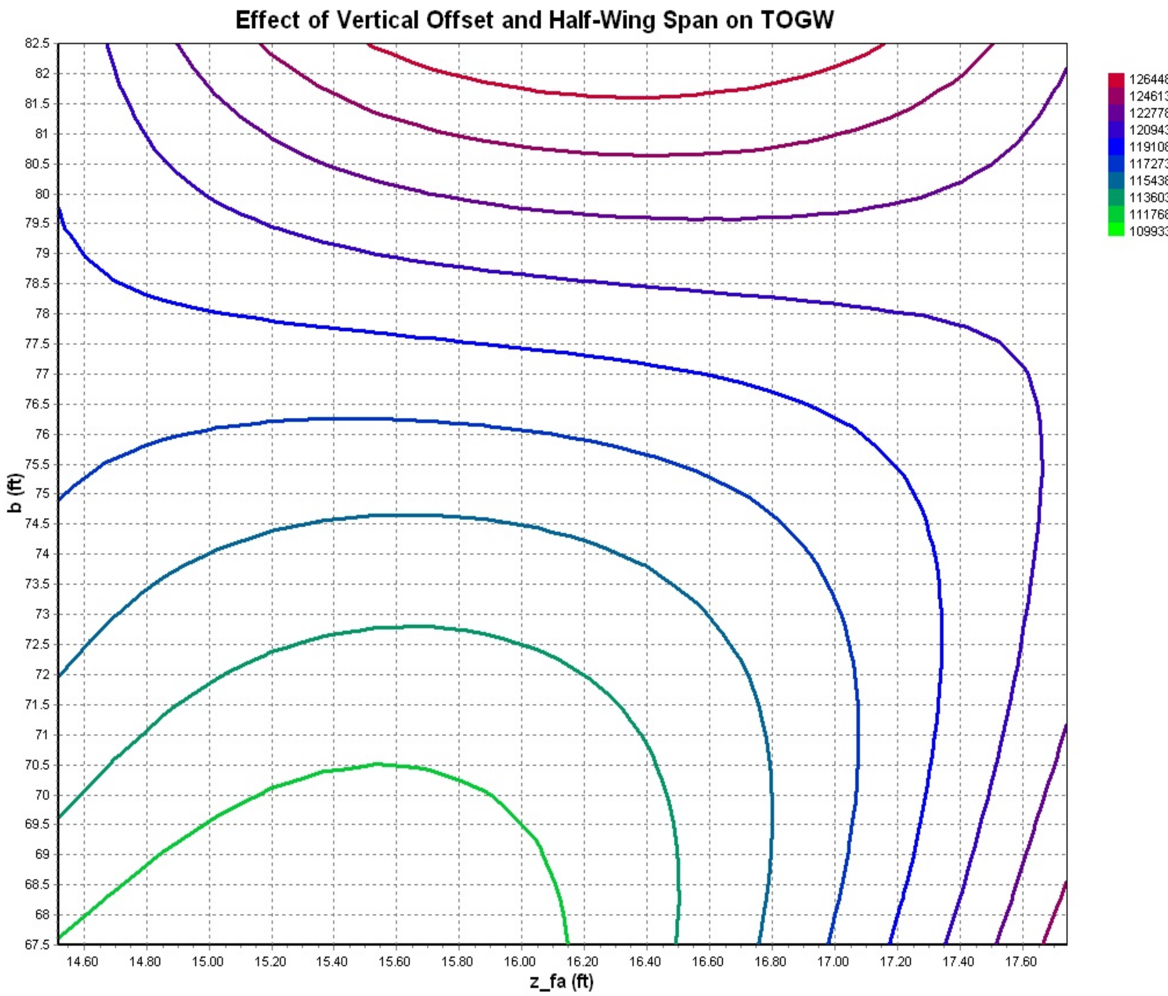
B-1

Effect of Joint Location and Half-Wing Span on TOGW

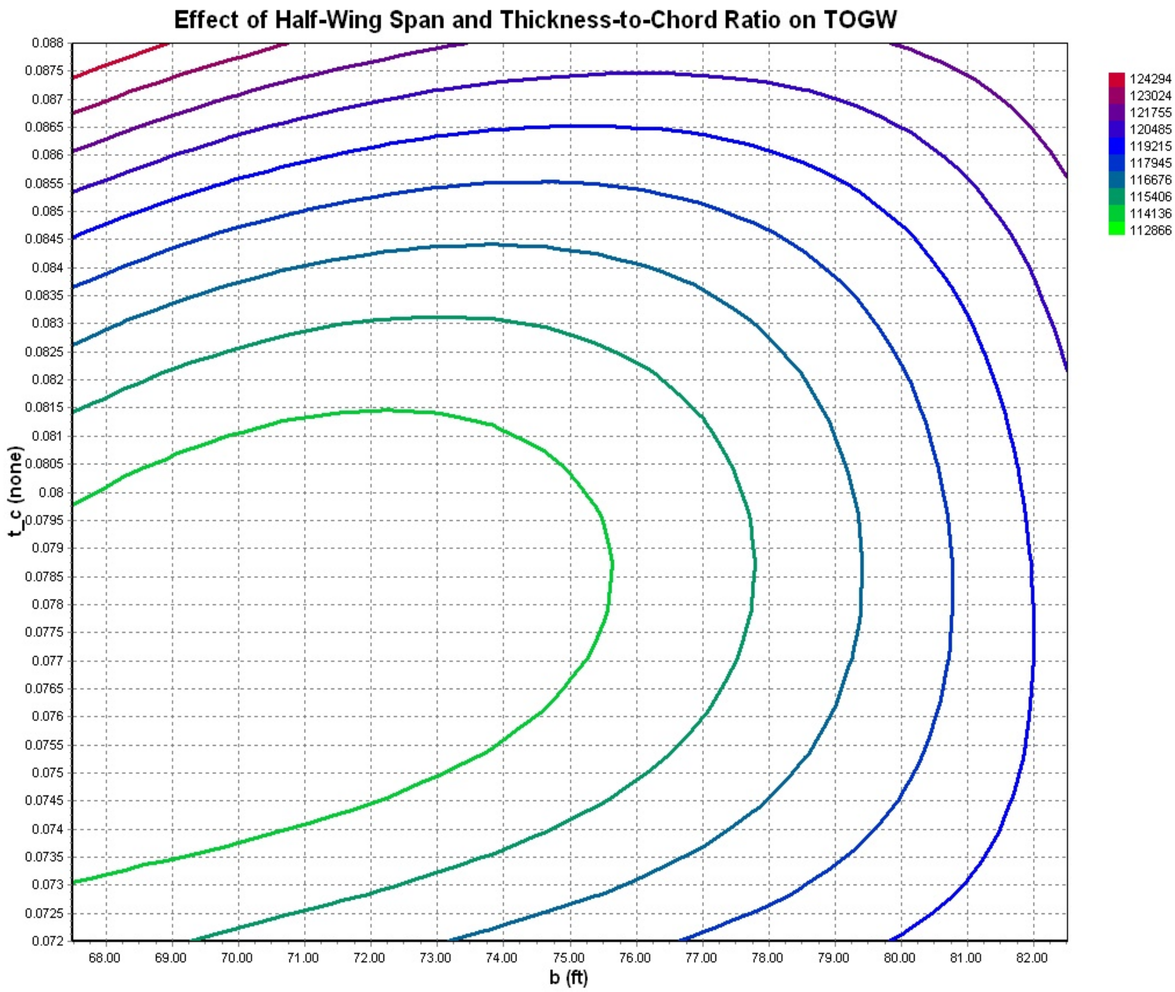


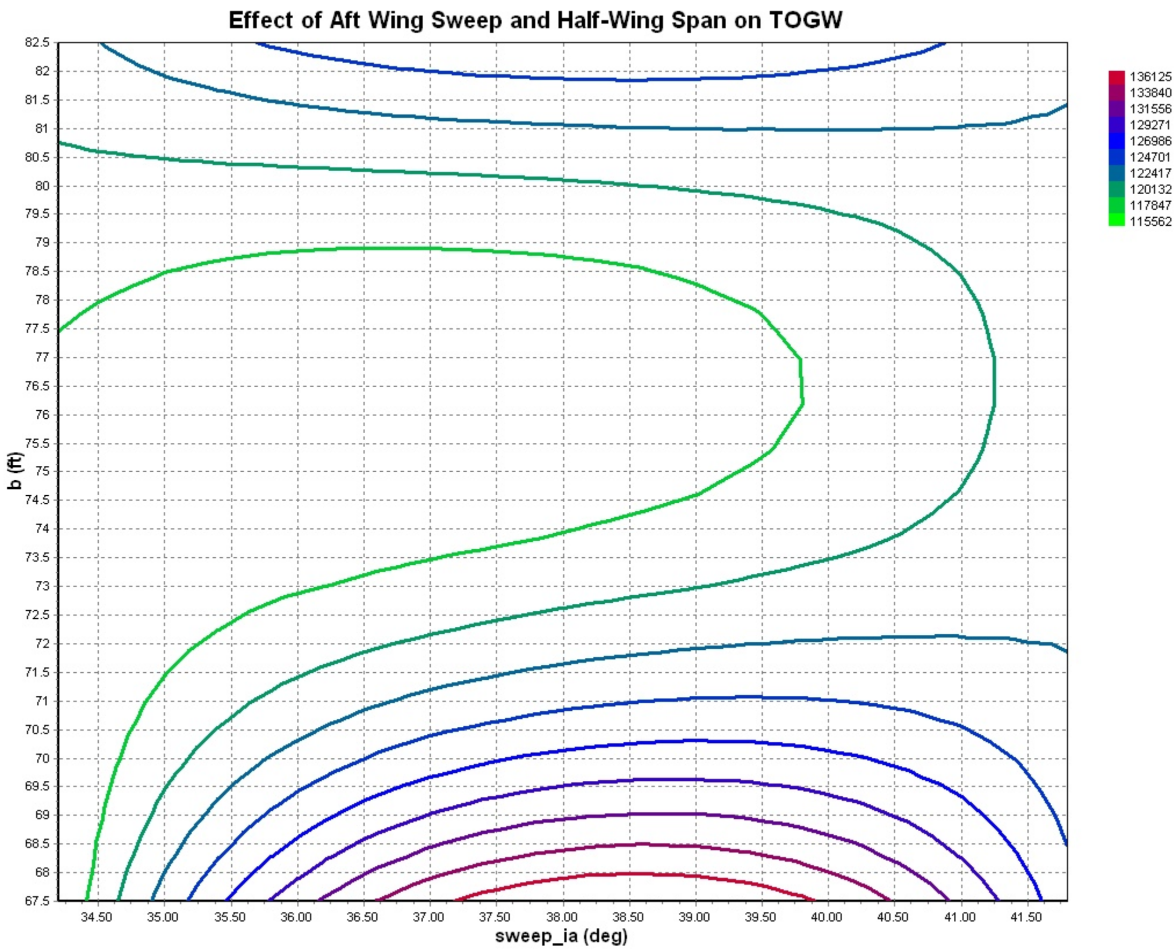

Effect of Inboard Sweep and Half-Wing Span on TOGW
b (ft)
sweep_ib (deg)
82.5
82
81.5
81
80.5
80
79.5
79
78.5
78
77.5
77
76.5
76
75.5
75
74.5
74
73.5
73
72.5
72
71.5
71
70.5
70
69.5
69
68.5
68
67.5
34.50
35.00
35.50
36.00
36.50
37.00
37.50
38.00
38.50
39.00
39.50
40.00
40.50
41.00
41.50
124476
123388
122299
121211
120123
119035
117947
116858
115770
114682

B-3

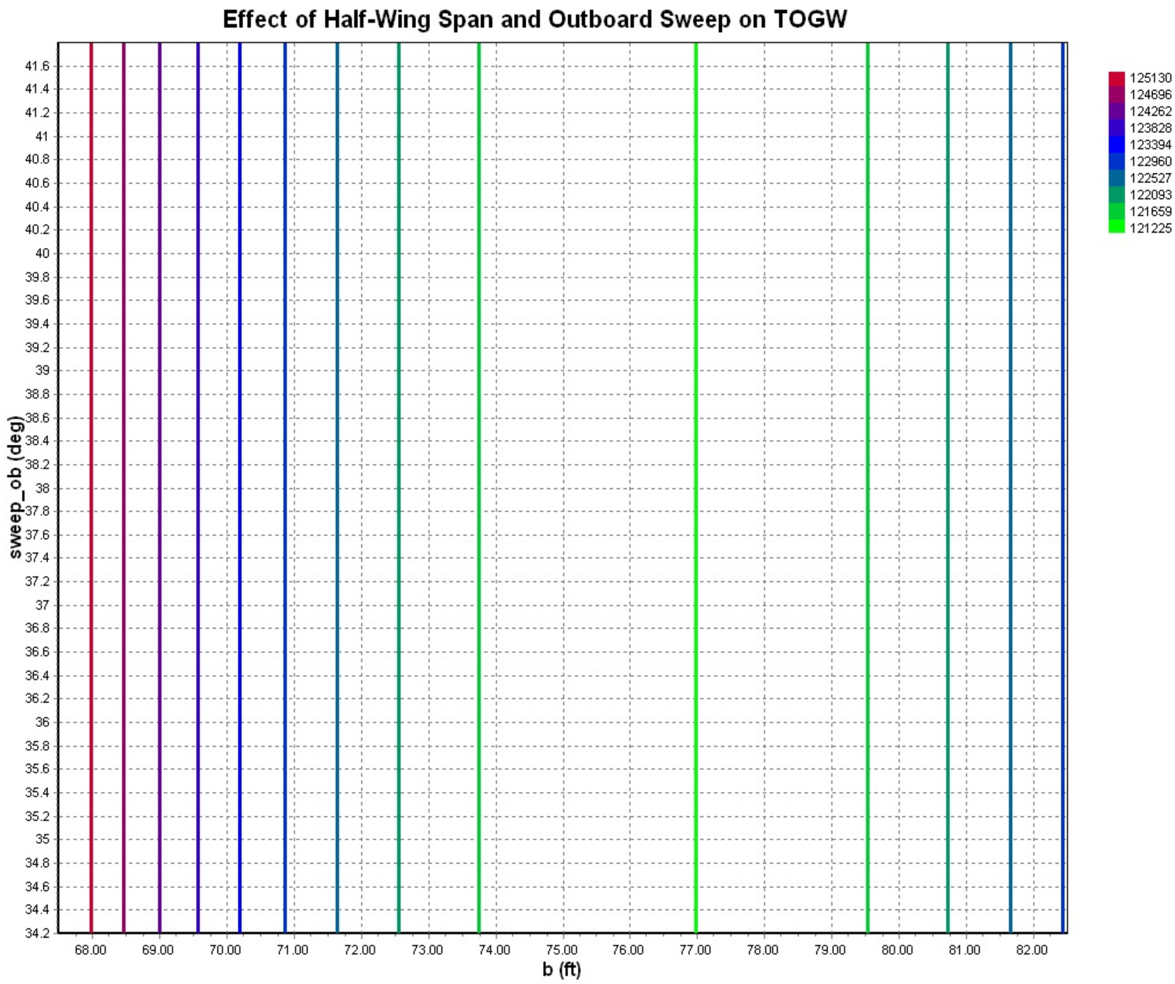

Effect of Vertical Offset and Half-Wing Span on TOGW
b (ft)
z_fa (ft)
82.5
82
81.5
81
80.5
80
79.5
79
78.5
78
77.5
77
76.5
76
75.5
75
74.5
74
73.5
73
72.5
72
71.5
71
70.5
70
69.5
69
68.5
68
67.5
14.60
14.80
15.00
15.20
15.40
15.60
15.80
16.00
16.20
16.40
16.60
16.80
17.00
17.20
17.40
17.60
126448
124613
122778
120943
119108
117273
115438
113603
111768
109933

B-4


Effect of Half-Wing Span and Thickness-to-Chord Ratio on TOGW
t_c (none)
b (ft)
124294
123024
121755
120485
119215
117945
116676
115406
114136
112866

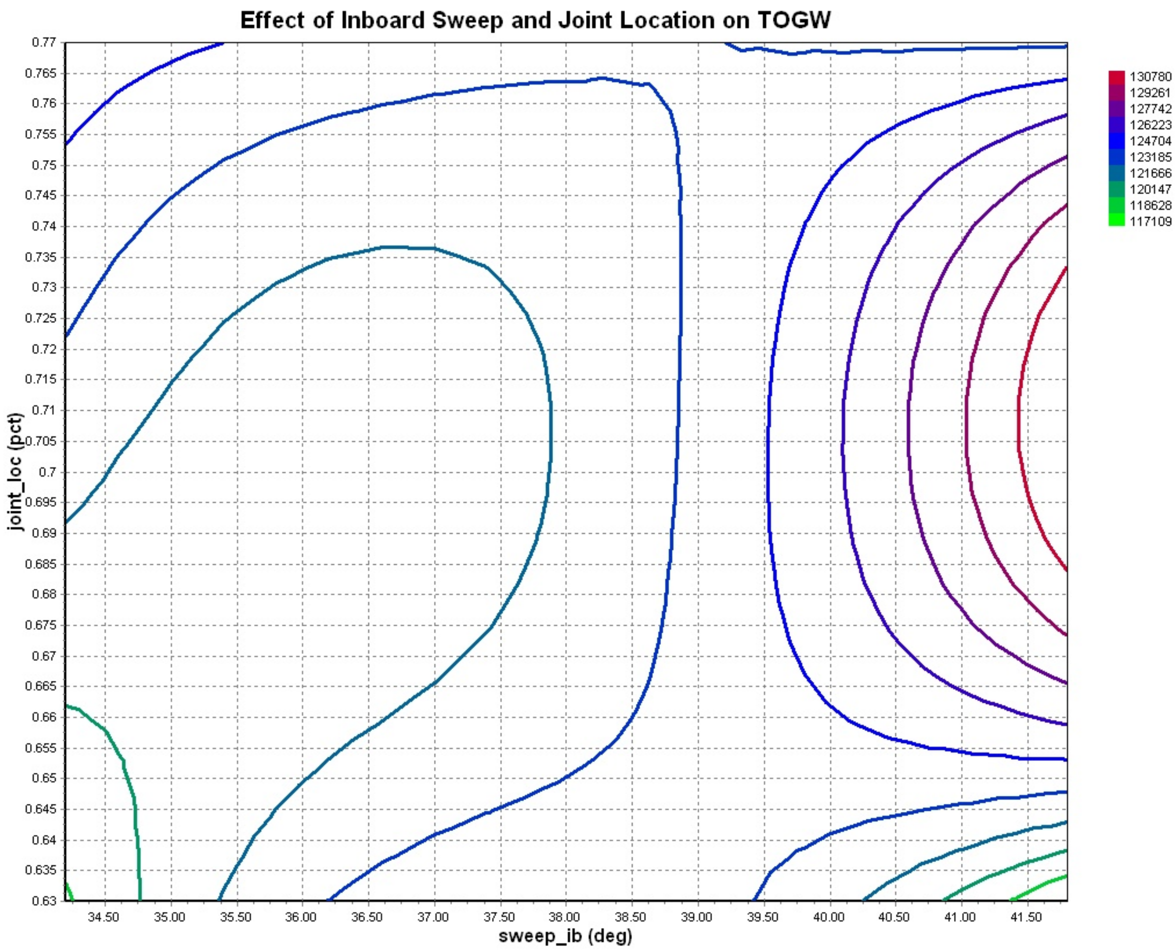

Effect of Aft Wing Sweep and Half-Wing Span on TOGW
b (ft)
82.5
82
81.5
81
80.5
80
79.5
79
78.5
78
77.5
77
76.5
76
75.5
75
74.5
74
73.5
73
72.5
72
71.5
71
70.5
70
69.5
69
68.5
68
67.5
34.50
35.00
35.50
36.00
36.50
37.00
37.50
38.00
38.50
39.00
39.50
40.00
40.50
41.00
41.50
sweep_ia (deg)
136125
133840
131556
129271
126986
124701
122417
120132
117847
115562

B-6



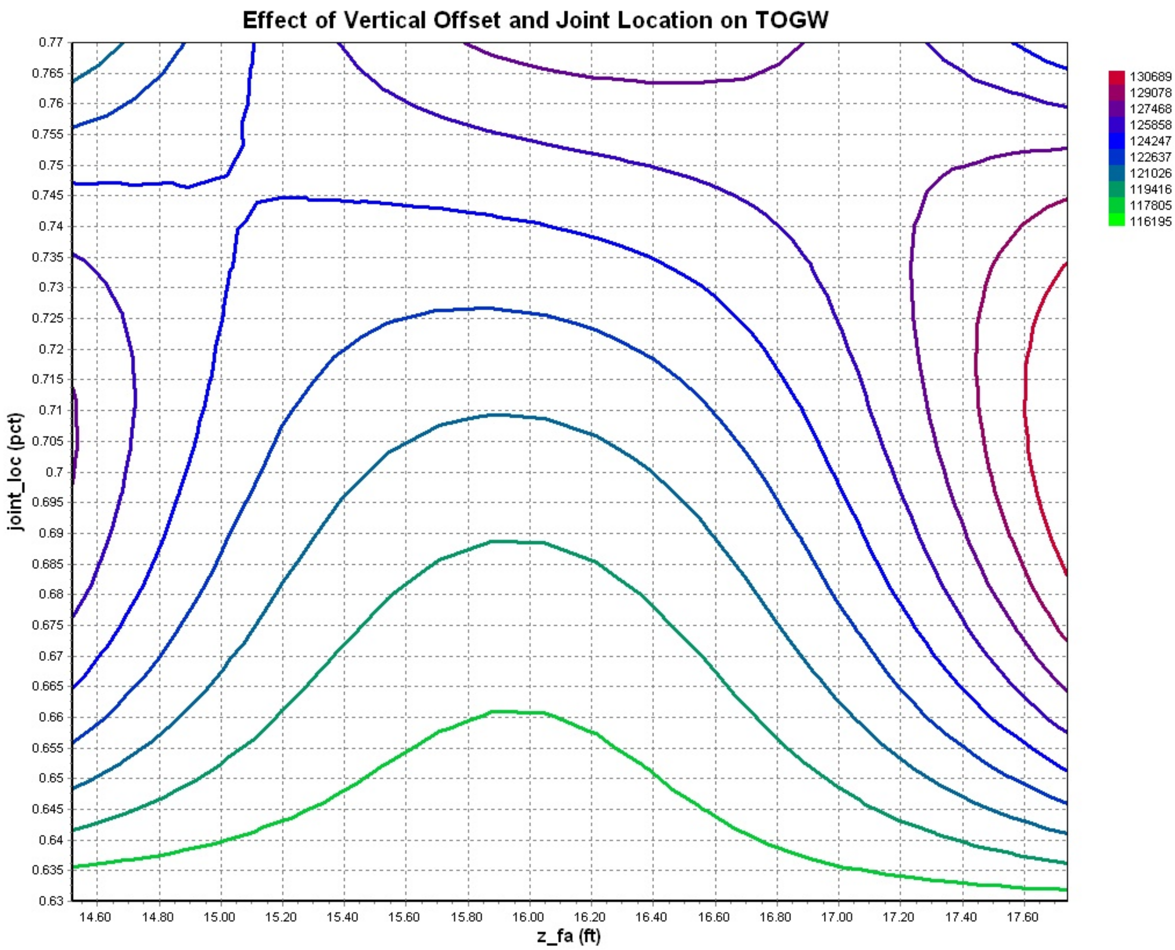
Effect of Half-Wing Span and Outboard Sweep on TOGW
sweep_ob (deg)
b (ft)
41.6
41.4
41.2
41
40.8
40.6
40.4
40.2
40
39.8
39.6
39.4
39.2
39
38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
37
36.8
36.6
36.4
36.2
36
35.8
35.6
35.4
35.2
35
34.8
34.6
34.4
34.2
68.00
69.00
70.00
71.00
72.00
73.00
74.00
75.00
76.00
77.00
78.00
79.00
80.00
81.00
82.00
125130
124696
124262
123828
123394
122960
122527
122093
121659
121225

B-7



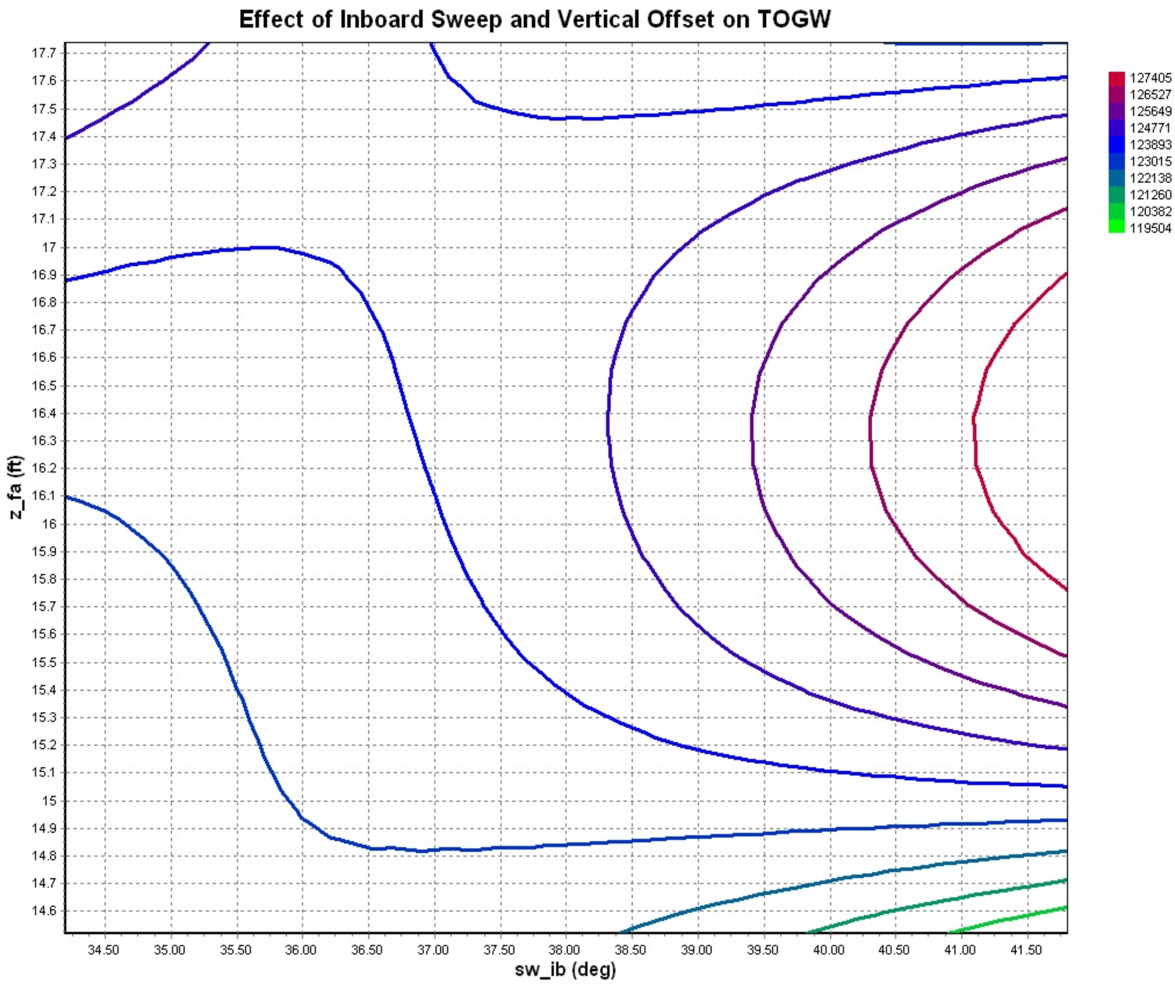
Effect of Inboard Sweep and Joint Location on TOGW
joint_loc (pct)
sweep_ib (deg)
0.77
0.765
0.76
0.755
0.75
0.745
0.74
0.735
0.73
0.725
0.72
0.715
0.71
0.705
0.7
0.695
0.69
0.685
0.68
0.675
0.67
0.665
0.66
0.655
0.65
0.645
0.64
0.635
0.63
34.50
35.00
35.50
36.00
36.50
37.00
37.50
38.00
38.50
39.00
39.50
40.00
40.50
41.00
41.50
130780
129261
127742
126223
124704
123185
121666
120147
118628
117109

B-8

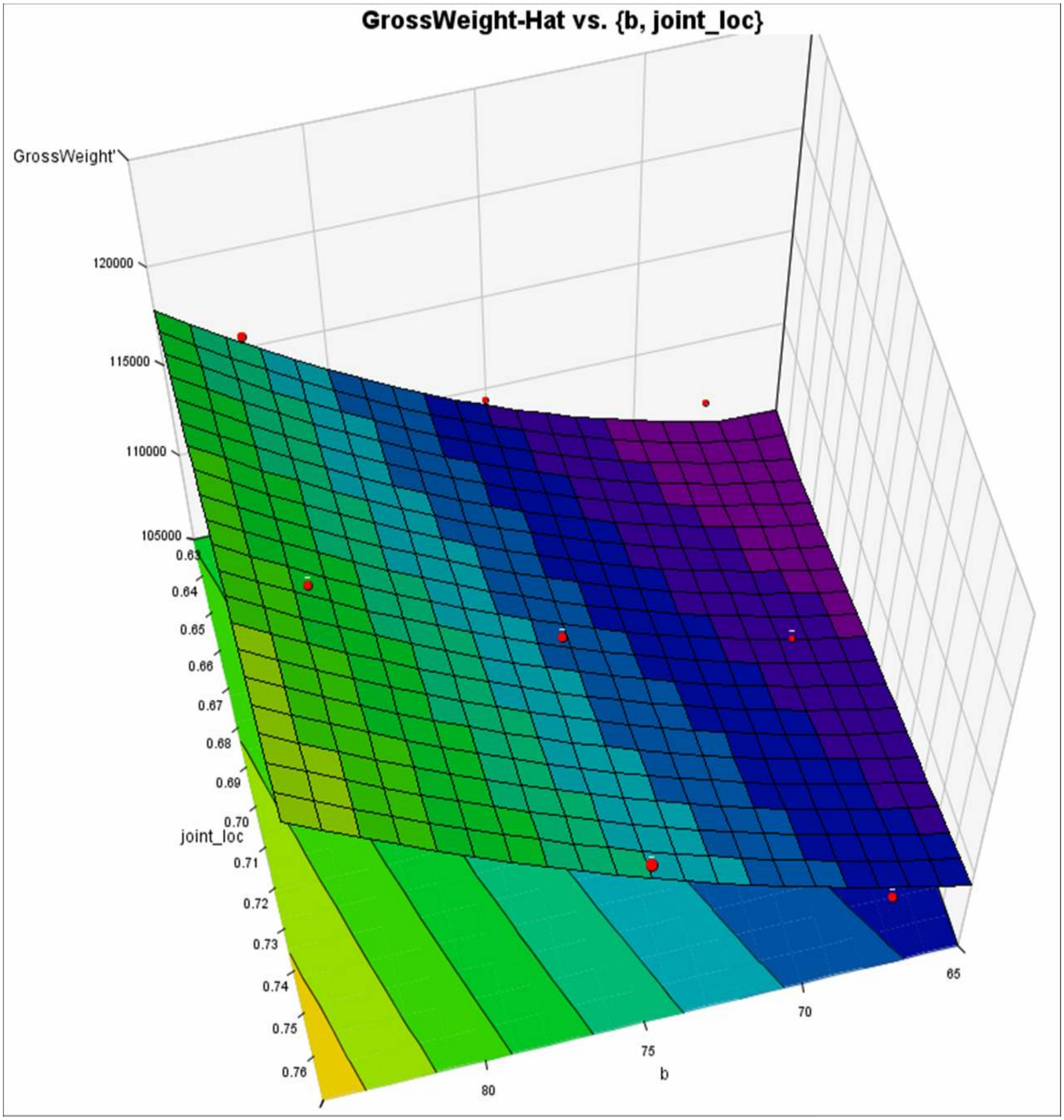


Effect of Vertical Offset and Joint Location on TOGW
joint_loc (pct)
z_fa (ft)
0.77
0.765
0.76
0.755
0.75
0.745
0.74
0.735
0.73
0.725
0.72
0.715
0.71
0.705
0.7
0.695
0.69
0.685
0.68
0.675
0.67
0.665
0.66
0.655
0.65
0.645
0.64
0.635
0.63
14.60
14.80
15.00
15.20
15.40
15.60
15.80
16.00
16.20
16.40
16.60
16.80
17.00
17.20
17.40
17.60
130689
129078
127468
125858
124247
122637
121026
119416
117805
116195

B-9


Effect of Inboard Sweep and Vertical Offset on TOGW
z_fa (ft)
sw_ib (deg)
127405
126527
125649
124771
123893
123015
122138
121260
120382
119504

B-10



GrossWeight-Hat vs. {b, joint_loc}
GrossWeight'
120000
115000
110000
105000
0.63
0.64
0.65
0.66
0.67
0.68
0.69
0.70
joint_loc
0.71
0.72
0.73
0.74
0.75
0.76
80
75
b
70
65

Appendix C: MATLAB Code (Super-Elliptical Generator)

```
% Fuselage Geometry -
% this file calculates the geometry (Surf_A and Vol) for an superelliptical cylinder
% Code is written in convention that x increases from nose to tail, y is positive out
right wing, z is up
% NOTE - variables must be at the top of the page with no space between them and the
comments
% setGroup "inputs"
% variable: rad1 double input
% variable: rad2 double input
% variable: rad3 double input
% variable: rad4 double input
% variable: length double input
% variable: superp double input
% variable: superq double input
% setGroup "adjustments"
% variable: yoff double input
% variable: zoff double input
% setGroup "sensitivity"
% variable: n double input
% variable: nn double input
% setGroup ""
% variable: Surf_A double output
% variable: Vol double output

%default variables
%rad1 = 0.1;       %ft (Vertical radius)
%rad2 = 0.1;     %ft (Horizontal radius)
%rad3 = 2;       %ft (Vertical radius)
%rad4 = 2;     %ft (Horizontal radius)
%length = 10;    %ft

%Superellipse parameters(if p=q=2 an elliptical shape follows, p=q=1 a diamond shape,
p=q=4 rounded rectangle)
%superp = 2; %Superellipse parameter p
%superq = 2; %Superellipse parameter q

%default adjustments (ellipse center offset(ft))
%assumes shape centered at (0,0,0) = (x,y,z)
%yoff = 0;%far end  %(Horizontal offset)
%zoff = 0;          %(Vertical offset)

%default sensitivity adjustments
%nn = 181;        %radial step-size, number of radial sections (721 gives right answer to
2 decimals (181 is fine))
%n = 10;          %longitudinal step size, number of longitudinal sections (10 is good)

%superq_1 = 4 %far end shape
%superp_1 = 4 %far end shape

nn4 = (((nn-1)/4)+1);
nn2 = (((nn-1)/2)+1);

l = length/n;    %incremental length

x(1) = 0;
r(1,1)= rad1; %vertical
r(2,1)= rad2; %horizontal
x(n+1) = length;
r(1,n+1)= rad3; %vertical
r(2,n+1)= rad4; %horizontal

%initial vectors
```

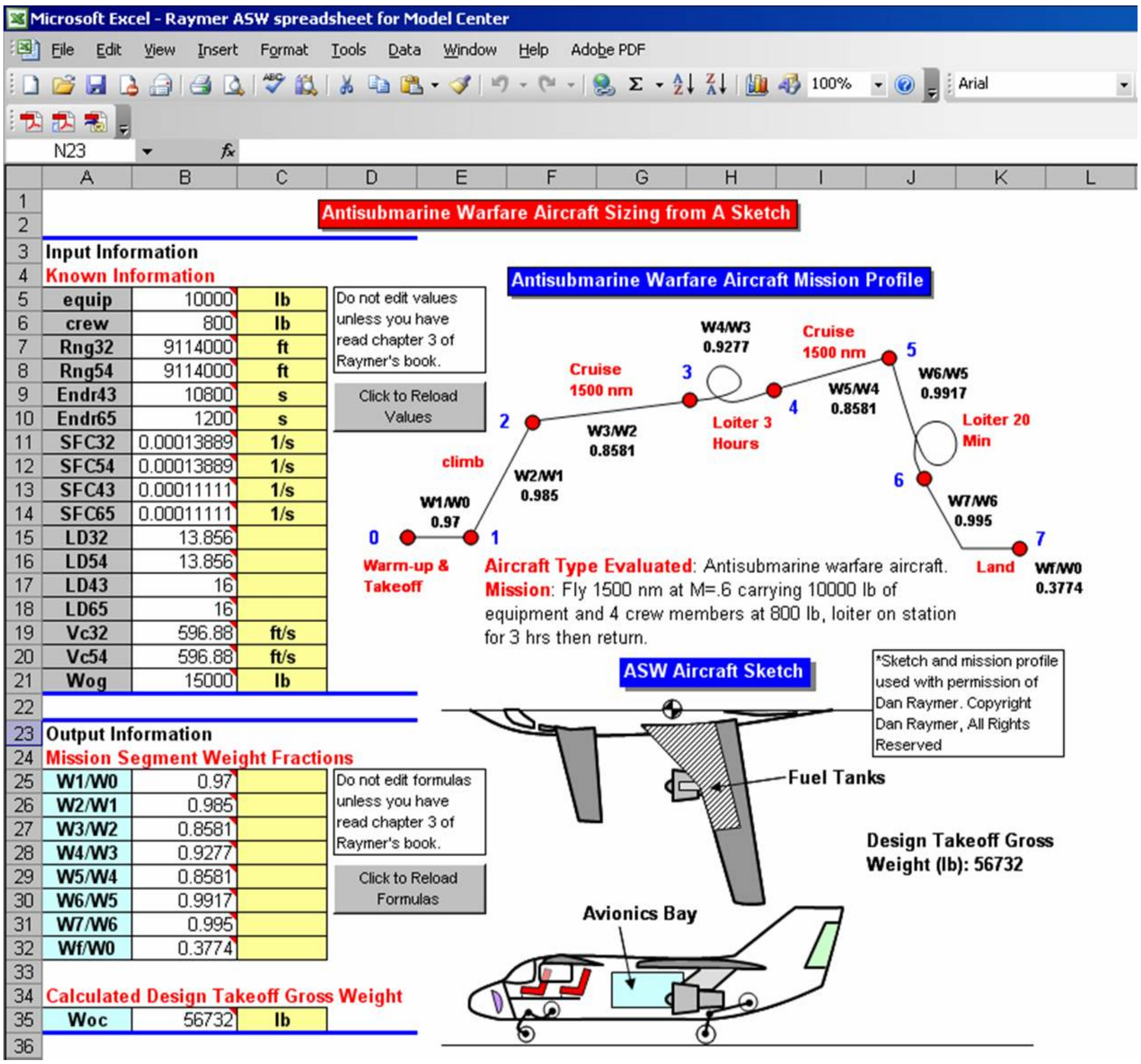
```
rad(1,1) = atan2((r(1,n+1)-r(1,1)),length);
deg(1,1) = rad2deg(atan2((r(1,n+1)-r(1,1)),length));
rad(2,1) = atan2((r(2,n+1)-r(2,1)),length);
deg(2,1) = rad2deg(atan2((r(2,n+1)-r(2,1)),length));
for j=1:2;
    for i=2:n;
        % theta vector %Not needed?
        x(i) = (i-1)*l;  % position in x
        rad(j,i) = atan2((r(j,n+1)-r(j,1)),length);
        deg(j,i) = rad2deg(atan2((r(j,n+1)-r(j,1)),length));
    end
    for i =2:n;
        r(j,i)= (l * tan(rad(j,i-1))) + r(j,i-1);
    end
end
surfdist = [];
for j = 1:2;
    for i = 1:n;
        surfdist(j,i) = sqrt((l)^2+(r(j,i+1)- r(j,i))^2);
    end
end
zero = [0;0];
surfdist = [surfdist, zero];
results = [x;r;surfdist];

yoffslope = -yoff/length;
zoffslope = -zoff/length;

% reset variables
sa = []; vol = [];

% Scroll through each ellipse
for j=1:n+1;
    % Calculate points on ellipse - Super Ellipse Generator
    a = x(j);
    yoff(j) = yoffslope* a;
    zoff(j) = zoffslope* a;
    super_p(j) = superp + ((superp_1 - superp)/n)*j;
    super_q(j) = superq + ((superq_1 - superq)/n)*j;

    %First Quadrant
    for i=1:nn4;
        b = ((cos ((i-1)*(360/(nn-1))*pi/180))^(2/super_p(j)))*r(2,j);
        c = ((sin ((i-1)*(360/(nn-1))*pi/180))^(2/super_q(j)))*r(1,j);
        if abs(a) < .0000001
            a = 0;
        end
        if abs (b) < .0000001
            b = 0;
        end
        if abs (c) < .0000001
            c = 0;
        end
        geom(i,3*j-2) = a;
        geom(i,3*j-1) = b;
        geom(i,3*j)   = c;
    end
    %Second Quadrant
    for i=nn4+1:nn2;
        geom(i,3*j-2) = a;
        geom (i,3*j-1) = - geom (nn4-(i-nn4),3*j-1); %Opposite
        geom (i,3*j)   = geom (nn4-(i-nn4),3*j);     %Same
    end
    %Third and Fourth Quadrants
    for i=nn2+1:nn;
        geom(i,3*j-2) = a;
        geom (i,3*j-1) = geom (nn2-(i-nn2),3*j-1);   %Same
        geom (i,3*j)   = - geom (nn2-(i-nn2),3*j);   %Opposite
    end
```

```
    %apply offsets
    for i=1:nn;
        geom (i,3*j-1) = geom (i,3*j-1)- yoff(j);
        geom (i,3*j)   = geom (i,3*j)- zoff(j);
    end
    %Determine distance between points
    for i=1:nn-1;
        diff (j,i)= sqrt((geom(i,3*j-1)-geom(i+1,3*j-1))^2 + (geom(i,3*j)-
geom(i+1,3*j))^2);
    end
    %Calculate Area and Perimeter
    peri(j) = sum(diff(j,:),2)*(cos(yoffslope)*cos(zoffslope));
    F = @(x) (1- (x./rad2).^super_p(j)).^(1/super_q(j)).*rad1;
    Q(j) = quadl(F,0,rad2);
    area(j) = 4*Q(j)*(cos(yoffslope)*cos(zoffslope))^2;
end
for j=1:n;
    % approximation of elliptical cylinder surface area (average of
    % perimeters * length) and volume (average area * length)
    sa (j) = (peri(j)+ peri (j+1))/2 * l/(cos(yoffslope)*cos(zoffslope));
    vol (j) = (area(j) + area (j+1))/2 * l/(cos(yoffslope)*cos(zoffslope)) ;
end

sa = [sa, 0];
vol = [vol,0];
results = [results; sa ; vol];
Surf_A = sum(sa ,2);
Vol = sum(vol,2);

%Plot Ellipses
%for j = 1:n+1;
%    plot3(geom(:,3*j-2),geom(:,3*j-1),geom(:,3*j),'LineWidth',2,'Color',[.6 1 0])
%   axis equal
%   hold on
%end

%Check for circular case
%VOLUME = rad1 ^2*pi*length
%AREA = rad1*2*pi*length
%Reduce Geometry
%181X33 is a bit much to display reduce to 37 points around shape evenly spaced by six
cross sections (3 x y z)
for j = 1:6; %10 = n (for j = 1:6) - Take 6 cross sections
    for i = 1:((nn-1)/45)+1; % 361 points (for i = 1:9) - Take every 22.5 degrees (9
points)
    reduced_geom (i,(3*(j-1)+1)) =  geom (45*(i-1)+1, 6*(j-1)+1);
    reduced_geom (i,(3*(j-1)+2)) =  geom (45*(i-1)+1, 6*(j-1)+2);
    reduced_geom (i,(3*(j-1)+3)) =  geom (45*(i-1)+1, 6*(j-1)+3);
    end
end
%for j = 1:6;
%    plot3(reduced_geom(:,3*j-2),reduced_geom(:,3*j-
1),reduced_geom(:,3*j),'LineWidth',2,'Color',[0 .6 0])
%    axis equal
%    hold on
%end
```

Appendix D: MATLAB Code (WingArea)

```
function [Volume,PlanArea,WetArea]=WingArea_Vol(airfoilname ,span, RTC, TTC, taperRatio,
rootChord);
% Computes approximate volume and wetted area for wing based on empirical
% calulations
avgChord = (rootChord + taperRatio * rootChord)/2;
avg_t_c = (TTC+RTC)/200;
PlanArea = span * avgChord

[areacoef,reflength,max_t_c]=AF_Acoef(airfoilname);

if avg_t_c < 0.05;
    WetArea = 2.003 * PlanArea                              % Raymer 7.10
    Volume = areacoef * avgChord * avg_t_c * PlanArea
else
    WetArea = PlanArea * (1.977 + 0.52 * avg_t_c)           % Raymer 7.11
    Volume = areacoef * avgChord * avg_t_c * PlanArea
end


function [areacoef,reflength,max_t_c]=AF_Acoef(airfoilname);
% Computes area coeficient (% of square area that occupied by airfoil)

%Load airfoil data
ext = '.mat';
filename = [airfoilname ext]
% AirFoil coordinates NACA 0016-63
valid = exist (filename);
if valid == 0;
    sprintf ('%s','That file does not exist. Default filename (0016) loaded.')
    sprintf ('%s','You need to first load airfoil data in x,y format, and save as .mat
file in the current directory')
    load 0016.mat; %default file
else
load (filename);
end

reflength = max (airfoilxy(:,1))       %Reference length of airfoil
max_t_c = max (airfoilxy(:,2)) * 2     %Symmetric Airfoils only
MaxArea = reflength * max_t_c
MaxAreaxy = [0 max_t_c/2
            0 -max_t_c/2
            reflength -max_t_c/2
            reflength max_t_c/2
            0 max_t_c/2];
Area_under = polyarea(airfoilxy(:,1), airfoilxy(:,2));
areacoef =Area_under/MaxArea

%Plot airfoil
%  plot (airfoilxy (:,1),airfoilxy (:,2));
%  axis equal
%  hold on
%  plot (MaxAreaxy (:,1), MaxAreaxy(:,2));

end
```

Appendix E: Excel Spreadsheet (Initial Sizing)



Input Information		
Known Information		
equip	10000	lb
crew	800	lb
Rng32	9114000	ft
Rng54	9114000	ft
Endr43	10800	s
Endr65	1200	s
SFC32	0.00013889	1/s
SFC54	0.00013889	1/s
SFC43	0.00011111	1/s
SFC65	0.00011111	1/s
LD32	13.856	
LD54	13.856	
LD43	16	
LD65	16	
Vc32	596.88	ft/s
Vc54	596.88	ft/s
Wog	15000	lb
Output Information		
Mission Segment Weight Fractions		
W1/W0	0.97	
W2/W1	0.985	
W3/W2	0.8581	
W4/W3	0.9277	
W5/W4	0.8581	
W6/W5	0.9917	
W7/W6	0.995	
Wf/W0	0.3774	
Calculated Design Takeoff Gross Weight		
Woc	56732	lb

Appendix F: MATLAB FEM Manipulation (modxyz.m)

```
function [xyzmod,bo,jloco,swiao,swibo,swobo,zfao,tco] =
modxyz(xyz,b,jloc,swia,swib,swob,zfa,tc,wbody,lbody,bo,jloco,swiao,swibo,swobo,zfao,tco)
%FEM transform equations for 410E model Joined_wing (for a sample xyz input)

%Sort the data into parts
for i =1:length (xyz);
    if xyz (i,4) == 1;
        in1 (i,:) = xyz (i,:);
    elseif xyz (i,4) == 2;
        in2 (i,:) = xyz (i,:);
    elseif xyz (i,4) == 3;
        in3 (i,:) = xyz (i,:);
    elseif xyz (i,4) == 4;
        in4 (i,:) = xyz (i,:);
    elseif xyz (i,4) == 5;
        in5 (i,:) = xyz (i,:);
    elseif xyz (i,4) == 6;
        in6 (i,:) = xyz (i,:);
    end
end
[r,c]= find(in1);
in1 = in1 (min(r):max(r),:);
[r,c]= find(in2);
in2 = in2 (min(r):max(r),:);
[r,c]= find(in3);
in3 = in3 (min(r):max(r),:);
[r,c]= find(in4);
in4 = in4 (min(r):max(r),:);
[r,c]= find(in5);
in5 = in5 (min(r):max(r),:);
[r,c]= find(in6);
in6 = in6 (min(r):max(r),:);

%Part (1) Body
%Eqn x(17)y()z(27,28)
%vars swob,swia,t/c,b no effect
for j = 1:length(in1);
    xo(j) = in1 (j,1);
    yo(j) = in1 (j,2);
    zo(j) = in1 (j,3);
    delZ = yo(j)*(zfao/2)*((1/(b*jloc))-(1/(bo*jloco)))...  %Eqn 27
        +  yo(j)*((zfa-zfao)/(2*jloco*bo));                  %Eqn 28
    delX = yo(j)*(tan(deg2rad(swib))- tan(deg2rad(swibo))); %Eqn 17
    delY = 0;
    out1(j,1) = in1(j,1) + delX;
    out1(j,2) = in1(j,2) + delY;
    out1(j,3) = in1(j,3) + delZ;
    out1(j,4) = 1;
end

%Part (2) ib
%Eqn x(17,19,23)y(20,24)z(29,38)
%vars swob,swia no effect
for j = 1:length(in2);
    xo(j) = in2 (j,1);
    yo(j) = in2 (j,2);
    zo(j) = in2 (j,3);
    delZ = zfa/2*((wbody/(jloc*b))+ ((yo(j)-wbody)/(jloco*bo - wbody))*((jloc*b-
wbody)/(jloc*b)))...
     - zfao/2*(wbody/(jloco*bo)+ ((yo(j)-wbody)/(jloco*bo - wbody))*((jloco*bo-
wbody)/(jloco*bo)))... %Eqn 29
     + zo(j) - (yo(j)/(jloco*bo))*(zfao/2)*(tc/tco);          %Eqn 38
    delY1 = yo(j)/jloco*(jloc-jloco);                        %Eqn 24
    delY2 = (jloc*b-jloco*bo)*((yo(j)-wbody)/(bo*jloco-wbody));  %Eqn 20
    delY = delY1+delY2;
```

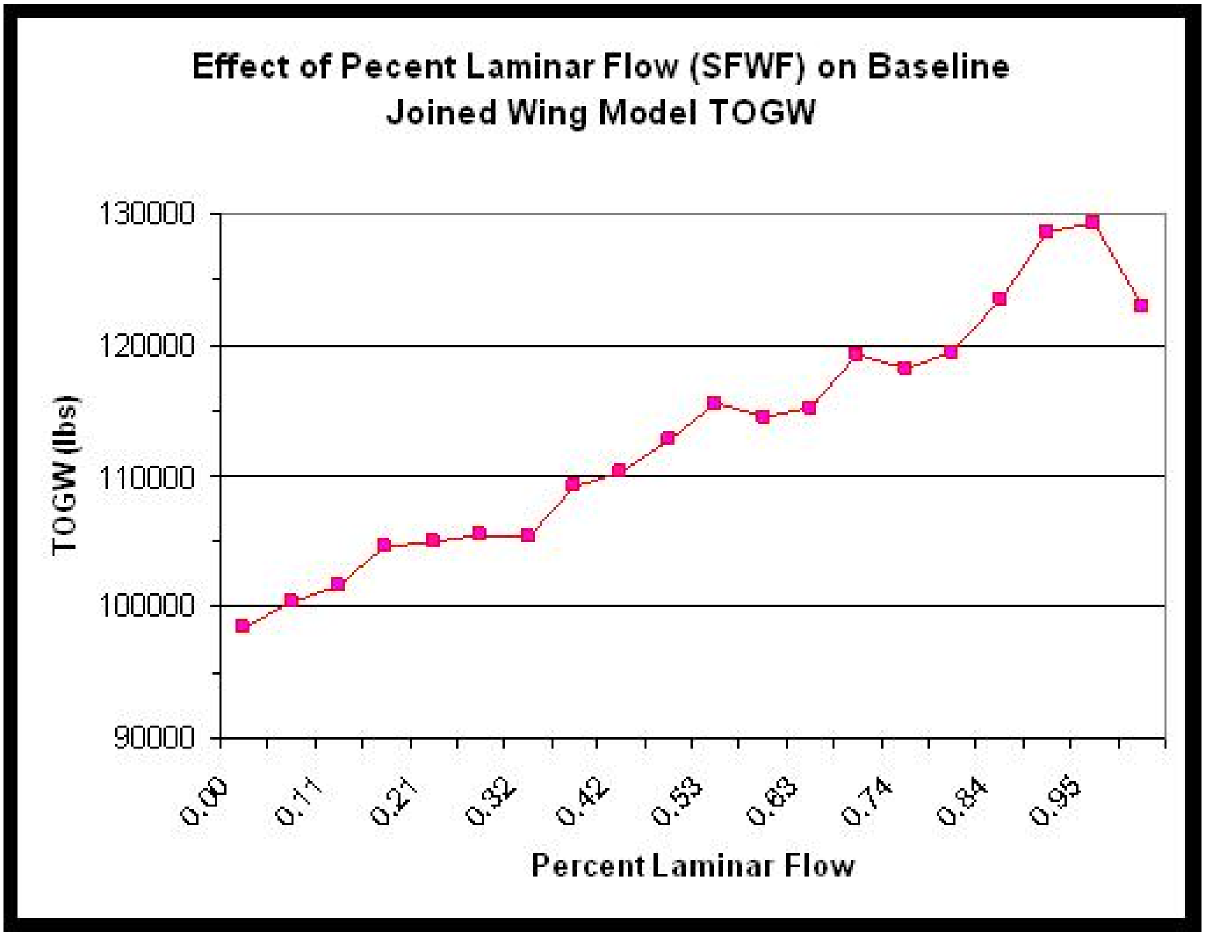
```
    delX = delY1*(tan(deg2rad(swib)))...                    %Eqn 19
        +  delY2*(tan(deg2rad(swib)))...                    %Eqn 23
        + yo(j)*(tan(deg2rad(swib))- tan(deg2rad(swibo))) ; %Eqn 17
    out2(j,1) = in2(j,1) + delX;
    out2(j,2) = in2(j,2) + delY;
    out2(j,3) = in2(j,3) + delZ;
    out2(j,4) = 2;
end

%Part (3) ob
%Eqn x(18,21,25)y(22,26)z(30,38)
%vars swia no effect
for j = 1:length(in3);
    xo(j) = in3 (j,1);
    yo(j) = in3 (j,2);
    zo(j) = in3 (j,3);
    delZ = ((yo(j)-jloco*bo)/(bo-jloco*bo))*((zfa/2)*(1/jloc))...
        -  ((yo(j)-jloco*bo)/(bo-jloco*bo))*((zfao/2)*(1/jloco))... %Eqn 30
        + zo(j) - (yo(j)/(jloco*bo))*(zfao/2)*(tc/tco);       %Eqn 38
    delY1 = (bo -yo(j))/(1-jloco)*(jloc-jloco);             %Eqn 26
    delY2 = (jloc*b-jloco*bo)*(1+ ((yo(j)/bo - jloco)/(1-jloco)));   %Eqn 22
    delY = delY1+delY2;
    delX = bo*jloco*(tan(deg2rad(swib))-tan(deg2rad(swibo)))+(yo(j)-
bo*jloco)*(tan(deg2rad(swob))-tan(deg2rad(swobo)))... %Eqn 18
        + tan(deg2rad(swib))* (jloc*b-jloco*bo)+ tan(deg2rad(swob))*(jloc*b-jloco*bo)*
((yo(j)/bo - jloco)/(1-jloco));          %Eqn 21
        %+ bo*(jloc-jloco)*(tan(deg2rad(swib)))+ bo*(2-jloc+jloco)*(tan(deg2rad(swob)));
%Eqn 25
    out3(j,1) = in3(j,1) + delX;
    out3(j,2) = in3(j,2) + delY;
    out3(j,3) = in3(j,3) + delZ;
    out3(j,4) = 3;
end

%Part (4) ia
%Eqn x(31,32,34)y(33)z(35,39)
%vars swob no effect
for j = 1:length(in4);
    xo(j) = in4 (j,1);
    yo(j) = in4 (j,2);
    zo(j) = in4 (j,3);
    delZ =  ((zfa-zfao)/2)*(1+((jloco*bo-yo(j))/(jloco*bo)))...                   %Eqn 35
        +   (zo(j)- ((zfao/2)+(zfao/2)*((bo*jloco-yo(j))/(bo*jloco))))*tc/tco;  %Eqn 39
(residual due to different model)
    delY = yo(j)/(bo*jloco)*(b*jloc-bo*jloco);                                  %Eqn 33
    delX = jloco*bo*(tan(deg2rad(swib))-tan(deg2rad(swibo)))...                 %Eqn 31
        +  (tan(deg2rad(swib)))*(b*jloc -bo*jloco) +...
        (tan(deg2rad(swia)))* (b*jloc -bo*jloco)*((bo*jloco-yo(j))/(bo*jloco))...  %Eqn
32
        + (jloco*bo - yo(j))*(tan(deg2rad(swia))- tan(deg2rad(swiao))) ;        %Eqn 34
    out4(j,1) = in4(j,1) + delX;
    out4(j,2) = in4(j,2) + delY;
    out4(j,3) = in4(j,3) + delZ;
    out4(j,4) = 4;
end

%Part (5) tail
%Eqn x(31,32,34)y(33)z(35)
%vars swob,tc no effect
for j = 1:length(in5);
    xo(j) = in5 (j,1);
    yo(j) = in5 (j,2);
    zo(j) = in5 (j,3);
    delZ =  ((zfa-zfao)/2)*(1+((jloco*bo-yo(j))/(jloco*bo)));                     %Eqn 35
    delY = yo(j)/(bo*jloco)*(b*jloc-bo*jloco);                                  %Eqn 33
    delX = jloco*bo*(tan(deg2rad(swib))-tan(deg2rad(swibo)))...                 %Eqn 31
        +  (tan(deg2rad(swib)))*(b*jloc -bo*jloco) +...
        (tan(deg2rad(swia)))* (b*jloc -bo*jloco)*((bo*jloco-yo(j))/(bo*jloco))...  %Eqn
32
```

```
        + (jloco*bo - yo(j))*(tan(deg2rad(swia))- tan(deg2rad(swiao))) ;        %Eqn 34
    out5(j,1) = in5(j,1) + delX;
    out5(j,2) = in5(j,2) + delY;
    out5(j,3) = in5(j,3) + delZ;
    out5(j,4) = 5;
end

%Part (6) boom
%Eqn x(36)z(37)
%vars swob,tc no effect
for j = 1:length(in6);
    xo(j) = in6 (j,1);
    yo(j) = in6 (j,2);
    zo(j) = in6 (j,3);
    delZ =  ((xo(j)- lbody)/((jloc*b)*(tan(deg2rad(swib))...
        + tan(deg2rad(swia)))- lbody))*(zfa-zfao);                              %Eqn 37
    delY = 0;
    delX = (zo(j)/zfa)* (jloc*b*(tan(deg2rad(swib))+ tan(deg2rad(swia)))...
        - jloco*bo*(tan(deg2rad(swibo))+ tan(deg2rad(swiao))));                %Eqn 36
    out6(j,1) = in6(j,1) + delX;
    out6(j,2) = in6(j,2) + delY;
    out6(j,3) = in6(j,3) + delZ;
    out6(j,4) = 6;
end

xyzmod = [out1;out2;out3;out4;out5;out6];

%AT END *** Need to reset new design variables to old design variables
swibo = swib;
swiao = swia;
swobo = swob;
zfao = zfa;
jloco = jloc;
tco  = tc;
bo    = b;
```

Appendix G: Response Surface Model Standard Analysis of Variance (ANOVA) Summary

```
Full Quadratic plus Cubic Interaction Terms

 Response Transformation: Z=Y (None)

 SOURCE           DF                 SS                 MS                  F    Fsig(%)

 REGRESSION       112    0.5000519E+00011  0.4464749E+00009  0.6780270E+00002     0.0000

 RESIDUAL ERROR   ***    0.1272205E+00011  0.6584913E+00007

 TOTAL            ***    0.6272724E+00011

 --------------------------------

  DATA FOR RESPONSE VARIABLE (Y)

 --------------------------------

 S          = 0.2566108E+00004

 Yavg       = 0.1151893E+00006

 CoV        =            2.23%

 R-Sq       =           79.72%

 R-Sq(adj)  =           78.54%
```

Appendix H: Effect of Laminar Flow (SFWF) in ACSYNT on TOGW



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14. ABSTRACT

A multidisciplinary conceptual design and analysis of Boeing's joined-wing SensorCraft has been conducted. This analysis was completed using geometrical optimization, aerodynamic analyses, and response surface methodology on a composite structural model. Phoenix Integration's Model Center was used to integrate the sizing and analysis codes found in Raymer's text, "Aircraft Design: A Conceptual Approach" as well as those from the NASA derived conceptual design tool AirCraft Synthesis (ACSYNT), and a modified Boeing Finite Element Model (FEM). This research demonstrated the utility of integrated low-order models for fast and inexpensive conceptual modeling of unconventional aircraft designs.

15. SUBJECT TERMS

SensorCraft, ModelCenter, Design of Experiments (DOE), Multi-Disciplinary Optimization (MDO), MATLAB

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